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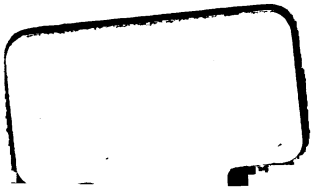

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DEPARTMENT OF THE INTERIOR

# BULLETIN

OF THE

# UNITED STATES

# GEOLOGICAL SURVEY

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Dec. 1890

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UNITED STATES GEOLOGICAL SURVEY
J. W. POWELL, DIRECTOR

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# THE GLACIAL BOUNDARY

IN

## WESTERN PENNSYLVANIA, OHIO, KENTUCKY, INDIANA, AND ILLINOIS

BY

GEORGE FREDERICK WRIGHT

WITH AN INTRODUCTION BY THOMAS CHROWDER CHAMBERLIN

WASHINGTON
GOVERNMENT PRINTING OFFICE
1890

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# LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF GLACIAL GEOLOGY,
*Washington, D. C., May* 23, 1889.

SIR: I have the honor to transmit herewith for publication as a bulletin of the Survey a paper prepared by Prof. G. Frederick Wright on the glacial boundary in western Pennsylvania, Ohio, Kentucky, Indiana, and Illinois, to which I have prefixed an introduction reviewing certain questions of wide interest and debatable interpretation.

Very respectfully,

T. C. CHAMBERLIN,
*Geologist in Charge.*

Hon. J. W. POWELL,
*Director U. S. Geological Survey.*



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# INTRODUCTION.

By T. C. Chamberlin.

The following paper is one of a series of important contributions to glacial geology, issued under different auspices, whose objects are to set forth the extent of the northern ice-borne drift with greater precision and detail than have been before practicable. In a general sense, the extent of the drift of the Atlantic border region and of the interior has long been known, but more or less lack of precision respecting its limits and marginal character has prevailed. In the western part of our territory definite knowledge has been much more limited and misconceptions of some gravity have obtained. No other state of knowledge was to be expected in view of the vast stretch of territory involved and the multiplicity of broad questions forced upon the attention of the earlier geological surveys, whose functions were rather to determine the salient features of a score of diverse formations than to trace out into complete detail any selected one. But about a decade ago (1876) a movement in the direction of more careful delineation of the outer margin of the drift was initiated by Profs. George H. Cook and John C. Smock, of the New Jersey Survey, and this was followed, at short intervals, by similar work on the southern border of New England by Warren Upham and other volunteers; across Pennsylvania by Profs. H. C. Lewis and G. F. Wright, under the auspices of the Geological Survey of that State; and across Ohio and Indiana by Prof. Wright, through the aid of the Western Reserve Historical Society. The present bulletin includes the extension of this work of delimitation to the Mississippi River, under the auspices of the U. S. Geological Survey. West of the Mississippi considerable progress has been made by Profs. R. D. Salisbury, J. E. Todd, and myself in delimiting the northern drift and determining the character of its border, but the details yet await publication. In the main the consecutive tracing of the border of the drift has not been attempted in that region, but determinations have been made at frequent intervals along the margin in connection with other work, deemed, at the present stage, more important.

All those who have been engaged in these recent and more careful studies of the border of the drift, though they have come to the study from different associations and under different auspices, have given



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assent in greater or less measure to the doctrine of the glacial origin of the drift, and have employed its working hypotheses. All are not, however, equally exclusive in their employment of these hypotheses. At present a portion of the investigators incline to the view that all the marginal deposits, save, obviously, the water-washed gravels, sands, and clays, are of direct glacial deposition, while others are undecided respecting *certain portions*, doubting whether they were deposited directly by land ice or indirectly by floating ice in bodies of water marginal to the great ice field.

There are also important differences of view respecting the unity of the marginal deposits and the continuity of the history of glaciation. Some of the investigators appear to give adhesion to the belief that the entire margin was produced at practically the same time and by the same great field of ice, while others entertain the confident belief that different portions of the margin were produced at different times and by independent ice invasions, or, at least, ice advances. These divergences of belief and these withholdings of belief constitute a wholesome intellectual environment which it is not desirable should be replaced by complete unity of interpretation until such unity shall be compelled by the force of evidence. It is essential, however, to its wholesomeness that the fact and the nature of the divergences should be distinctly understood wherever confusion or misapprehension are liable to be introduced into the literature of the subject, and wherever the general reader, who has not traced critically the growth of opinion, may otherwise be misled.

Certain of these divergences of view and certain more specific differences of opinion, to which attention will presently be called, exist between the author of this paper and myself, in view of which Prof. Wright in transmitting this paper indicated that it would cause him no surprise if I should express dissent from some of the views advocated in this bulletin. It seems to me consonant, therefore, with a full appreciation of the obviously great value of the data here presented, to call attention to certain points of divergent interpretation.

The first difference of opinion springs from the marked diversities which the character of the drift border presents.[1] In the Atlantic and Appalachian regions the margin is generally marked by ridged accumulations, bearing the specific characters of a terminal moraine, whereas in the Mississippi Valley and on the plains west of it the drift ends in a thin margin, unmarked by specific terminal ridging. The bordering

[1] The diverse characters of the drift margin appear to have been first clearly distinguished on the border of the driftless region of the Upper Mississippi, and were specifically discussed by my associate, Prof. R. D. Salisbury, before the Wisconsin Academy of Science in 1884, who set forth the contrasted facts that along certain stretches the margin consists of thick-ridged accumulations, constituting definite terminal moraines, while along other stretches the drift ends in attenuated edges. The subject is more fully brought out in our joint paper on the driftless area of the upper Mississippi Valley, in the Sixth Annual Report of the U. S. Geological Survey.

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moraine at the east departs from the extreme limit of drift, according to our present knowledge, as I interpret it, in western Pennsylvania. There the outermost moraine[1] lies a few miles back from the limit of drift, the extreme edge being formed of thinly dispersed erratics. Westward from this there is a wider departure of the two, and in the immediate valley of the Mississippi the terminal moraines thus far identified lie remote from the border. I have elsewhere assigned reasons for believing that these are the essential equivalents of the ridges which lie along the border in the Atlantic region. However this may be, I entertain the view that the drift sheets of the interior which terminate in attenuated borders—and I hold that there are more than one of these—are more ancient than the drift which terminates in the recognized ridged moraines. I conceive that these differently disposed drifts indicate somewhat widely separated epochs of glaciation, attended by differences of orographic attitude and differences in the specific methods of action and in the phases of deposition.

If there be any truth in these views it becomes important to distinguish the differences in the character of the border, for they have significance beyond the mere fact of variation in the manner of deposition. While not disposed to urge the acceptance of these views beyond the point to which they seem to be borne out by specific evidence—which can not, obviously, be here cited—it seems important that the differences in the nature of the border be duly weighed, and that pending the demonstration of the truth the mind of the reader be withheld from the unconscious acceptance of the impression, which has somewhat obtained, that the border is a historical unity.

Respecting the question of mode of formation it is most important that the criteria of discrimination between deposits held to be formed directly by land ice and those held to be formed by floating ice should be rigorously scrutinized. The criterion of *striation*, as urged by the author of this bulletin, appears to me to be thoroughly trustworthy where the scorings are developed in sufficient abundance and perfection to afford ample facilities for discrimination. In the Atlantic and Appalachian regions and over large portions of the interior the phenomena of *striation* are adequate and decisive, but near the border, in the plain region of the interior, striation is relatively rare and feeble. Besides, there are very numerous instances of unabraded, rotten-surfaced rock, covered with the ancient residuary material, and even old soils remain unremoved. This appears to force the alternative of either dismissing the land-ice theory for these areas or of maintaining that land ice may creep over extensive tracts without forcefully abrading the surface, even when already incoherent from disintegration. While I incline to the latter alternative somewhat strongly, it appears to me to be in the interest of ultimate progress to distinctly recognize the differences between such areas of feeble abrasion and those which exhibit

[1] Using the word here only in the sense of a terminal *ridging* produced by a glacier.

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strong glacial rasping, and also to recognize that while the land-ice hypothesis is unassailable in the one region, its support is relatively weak and perhaps altogether insufficient in some portions of the other; and further to recognize that while the glacial theory may be true in the main it may be false in the particular.

The evidence afforded by the tills seems to me yet to need adjudication. While, generally, unassorted, unstratified bowlder clays are strong presumptive evidence of glacier origin, there seems yet to be reason to believe that almost precisely similar deposits may be produced by the droppings of floating ice. Certainly the presence of glaciated pebbles and bowlders is not distinctive, for floating ice derived from the edge of an adjacent or distant glacier would bear material precisely like that carried within the glacier itself. That it might be unstratified in its deposition appears to be supported both by theoretical considerations and by observations on deposits which are so sandwiched between assorted and laminated material, so graduated into such material, and so bordered by beach lines and surfaced by plane topography as to afford strong evidence of glacio-natant origin. Having, without much satisfaction, puzzled over the problem for several years in the endeavor to find trustworthy lines of discrimination between bowldery clays of glacier and of glacio-natant origin, respectively, I am inclined to regard this line of proof as of doubtful character in its general application, though the specific nature of individual deposits may disclose their origin with reasonable certainty.

Evidence drawn from the topographic relations of the margin of the drift is of the first order of importance. In the present case the undulations of the margin over heights and across valleys constitute the strongest feature of the evidence. The free manner in which the border line rises and falls in crossing the Appalachian Mountains and the bordering hilly districts is scarcely less than demonstrative in itself. In the plainer regions of the Mississippi Basin similar evidence, though less pronounced in character, carries corresponding weight. Relying chiefly on this argument, a qualified assent seems required to the view of Prof. Wright that the extent of the ice was essentially coterminous with the extent of the drift.

Other criteria of discrimination between the products of land ice and of floating ice, respectively, are assignable. Among these the peculiar character of the products of drainage, particularly the overwash aprons and the moraine-headed gravel trains, have the highest value. Where these are strong and sharply developed, nothing can be more convincing of glacier origin, and nothing more fatal to the glacio-natant hypotheses. But if phenomena of this class are clearly developed in the debatable territory, they have not been determined with sufficient definiteness to be a source of appeal. On the contrary, the most notable attendant phenomenon is the loess-like silt that overspreads the margin and the adjacent regions, both within and without the border The graduation

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of this into the till of these districts—*not everywhere*—I esteem one of those features which demand a conservative attitude respecting the part played by creeping ice and by floating ice, respectively.

As a check in the opposite direction, it is to be noted that there is, thus far, a lack of evidence of shore lines, or of definite horizontal limitations of the supposed subaqueous products, such as might reasonably be expected under the hypothesis of subaqueous deposition.

While, therefore, on the whole, the evidence seems to me quite strongly to support the view advocated in this paper, that the advance of the land ice was essentially coincident with the margin of the bowldery drift, such a view seems tenable only on the hypothesis that the land ice was competent to creep out upon a plain without forceful action upon it, and without notably plowing up material at its edge.

This seemingly necessary qualification respecting the marginal action of the ice must be carried with us as we turn to the consideration of the supposed glacial dam in the vicinity of Cincinnati. I assent to the view of Prof. Wright and of the earlier students of the drift south of the Ohio River, notably Dr. George Sutton,[1] that the ice sheet probably pushed across the river and landed the bowldery drift south of it essentially in its present position. But there is a lack of evidence that this involved forceful or vigorous action, for striation and abrasion have not been detected, and the amount of transported drift is trivial. The glacial action here appears to have belonged to the ineffective class above alluded to. *The fact, therefore, that the ice bridged the chasm of the Ohio does not necessarily carry with it the view that it blocked that chasm to the exclusion of the river.* It does not follow that there was a permanent glacial dam at that point, competent to backset the water to the height of the five or six hundred feet requisite to give it some other outlet. It may be admitted as extremely probable that the temporary damming of the stream by ice gorges was of frequent occurrence, and still be held that, in the main, the water maintained a tunnel under the overbridging ice. Such tunnels are not uncommon beneath existing Alpine glaciers, where they push across the mouth of tributary valleys. There is a wide distinction to be drawn between the obstruction caused by the thin extremity of a glacier creeping across the channel of a stream, and those instances (so numerous on the northward slopes during the later stages of glaciation) in which an enormous mass of thick ice, if not the great body of the glacier itself, pushed against the ponded waters. The Mergelen Lake, of Switzerland, is one of the few known instances of an ice-dam and body of water of the former order, and we have in it some indication of the competency of ice to act as a permanent dam under such conditions. The great Aletsch Glacier flows across the mouth of a tributary valley and dams back a brook, forming a little lake, to which the name Mergelen See is given. The glacier extends past the mouth of the tribu-

[1] Proc. Am. Assoc. Adv. Sci., 1876, pp. 225-231; Geol. Survey Indiana, 1878, pp. 108-113.



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tary about 9,500 meters, and proves itself competent to form a temporary dam, but not a permanent one, though the depth of the backset water is here only about fifty feet. This comparatively slight depth of water, giving a pressure of little more than an atmosphere and a half, periodically bursts its way out beneath the ice, and discharges itself in destructive floods down the valley. In the supposed ice-dam at Cincinnati, the pressure reached, by hypothesis, sixteen or seventeen atmospheres, or about two hundred and fifty pounds to the square inch, while the ice reached across the gorge scarcely more than twice the distance that the Aletsch Glacier passed beyond the mouth of the valley in which the Mergelen Lake lies.

Besides the great difference in the depth of water, there is the important fact that the Ohio Valley at all times bore a stream of great volume. In proportion as the ice encroached upon its channel, its current must have been accelerated, and its scouring ability increased, and with that arose an increased tendency to cut for itself a special narrow and deep channel less readily invaded by ice. Besides, the current must have been charged with sharp silt, derived from the glacial grinding on the north side of its basin, while the water from its southern side probably at all times retained some melting power, which, added to the heat of friction developed by the constricted and forced current, augmented its ice-cutting power and aided it in maintaining itself against the ice encroachment. Its situation in the bottom of a deep gorge, running transverse to the ice movement, and lying from four to six hundred feet below the plateau on which the overriding ice chiefly rested, also gave it an advantage in maintaining itself against the thin and relatively inert margin of the ice. Thus several conditions favored the stream in its struggle with the supposed encroaching glacier.

There would, however, seem to have been every requisite condition for the formation of gigantic ice-gorges at the time of the vernal breaking up of the river ice, and on other favoring occasions. But as soon as such an ice-gorge becomes an effective ice-dam, if it ever does—which is doubtful—it destroys the conditions of its own creation; first, by stopping the current that produced it and held it in place; and, secondly, by lifting the ice by the rise of the ponded water. It seems improbable that a lake so ponded would rise to a height of five or six hundred feet without lifting such a dam of blocks piecemeal, or even bodily. Certainly, with the known tendency of solid ice to form bergs, it could not be supposed to remain long.

But, as a matter of fact, it would probably never become a complete dam, and would soon be threaded by innumerable tunnels, whose gradual enlargement would lead to its destruction. Meanwhile, the escaping waters, though greatly reduced, might still be able to maintain a tunnel under the glacier, which, though it might be correspondingly reduced by the encroachment of the ice, would again be enlarged by the

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powerful current forced through it when the ice-gorge weakened or lifted.

It appears far from clear, therefore, that the existence of a permanent ice-dam was a necessary or even probable consequence of the slight crossing of the gorge by the glacier. Temporary and partial blocking I should deem an extremely probable and frequent occurrence, but not a permanent damming.

I am perhaps influenced in this view by a study of another region where the similar question of glacial damming has arisen. I refer to the driftless area of the upper Mississippi, which is surrounded on all sides by a deep sheet of drift. On the south, along the Mississippi, which was its drainage outlet, the country is occupied by drift for 250 miles; not merely a sprinkling of dispersed bowlders with exceptional patches of till, as in the trans-Ohio region, but a general mantle of drift. The driftless area has been diligently searched for evidence of temporary as well as permanent submersion. Along the western border there are scattered erratics and a mantle of loess, but over the central and eastern portions erratics are absent, except in extremely rare instances of probably human transportation. There is a very thin discontinuous distribution of fine silt mingled with the residuary soil and only distinguishable from it in most cases by the microscopic detection of minute particles of crystalline silicates and other minerals which are common to the drift and loess but not known to occur in the purely residuary soil. These foreign particles may, perchance, be wind-drift importations, or they may be the results of transient submersion; such a submersion as was possibly due to the temporary blocking of the outlet by ice. The distribution of the loess, however, does not form an argument for this view, for it spreads over the drift southward, reaching entirely across the glaciated tract. Whatever may be the truth respecting these trivial silt deposits, there has been found no proof of general and permanent submersion of this region by ice-damming, notwithstanding the conditions seem to have been exceptionally favorable therefor, and notwithstanding the further fact that the depth of water requisite for the submersion of most of the area is less than that postulated for the supposed Cincinnati dam.

But these theoretical considerations are less to our present purpose than a consideration of the direct evidences of the existence or non-existence of an effective blockade of the river at that point. Among the crucial tests of such a hypothesis may be enumerated the existence of lacustrine deposits and high shore-marks in the valley above, *but not below*. In an ideal case such lacustrine deposits and shore-marks should be present immediately above the dam, but not present within the area occupied by the dam nor immediately below. Terraces and supposed lacustrine deposits two or three hundred miles above are less conclusive, because of the possibility of intervening agencies.

A second crucial test of the hypothesis is to be found in the existence or

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non-existence of the abandoned channel through which the supposed ponded waters discharged themselves. It must be quite evident, upon consideration, that the ponded waters could not have had a permanent outlet across the ice itself, for such a stream as the Ohio, fed during the summer season with relatively warm waters from the southern half of its large basin, must quickly have cut a channel through the barrier. As yet no such outlet has been found, or, at least, determined to be such, and the hypothesis lacks this very important support.

These considerations lead up to the much discussed terraces of the upper Ohio, Monongahela, and Alleghany valleys, which have been thought by Professors Wright, White, and Lesley to have had their cause in the supposed ice-dam, and in turn to afford evidence of its existence. As a widely different interpretation of the origin of the chief terraces of these streams seems to me required, it is the part of candor to specifically set forth this divergence of view in transmitting this bulletin to the scientific public.

I look upon the determination of the origin of these terraces as chiefly a question of identification of structural species, quite analogous to the identification of species of plants and animals. Terraces formed by bodies of standing water are specifically different from those formed by flowing water, and the question here is, Have these terraces the inherent characters of lake and sea terraces or those of river terraces? The following are among the specific differences which should enable us to distinguish the class to which they belong. They are drawn with special reference to terraces in a system of branching, narrow valleys, as in the case in hand. They would require some amplifications and qualifications for a different habitat.

*Lacustrine terraces are horizontal, while fluvial terraces slope in the direction of the river flow.* In the case of terraces formed by rivers that have nearly reached their base plains the slope is obviously slight, but the basis for discrimination still remains. The intervention of crust movements may obscure, but can scarcely obliterate, the distinction, for in a system of tortuous and branched valleys, as in the present case, the system bears in itself the data for the elimination of the distortion.

Limiting attention for the moment to constructive terraces, it is the rule that lacustrine terraces are built throughout the entire circuit of the lake, while fluvial terraces are built only in favoring lodgment spots, as the concave bends of the meandering stream. The tendency in the one is to uniformity of distribution; in the other to local aggregation. Both tendencies are subject to important modifications, but these modifications are likewise distinctive. The two more important modifications are caused by (1) the difference in the extent of the sweep of the waves, and (2) by the material brought in by tributaries.

(1) Other things being equal, lacustrine terraces (whether wave-cut terraces or wave-built terraces) are greatest opposite the longest sweep

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of the waves, and, the sweep being equal, are greatest opposite the sweep of predominant winds. The strength of development of lacustrine terraces corresponds, therefore, to the stretch of water opposite to them and to their relation to prevailing winds. In river terraces wind action is overshadowed by other agencies, and the above correspondences are wanting. The more extensive the series of terraces and the more varied their positions relative to the extent of water surface and to the direction of winds the more pronounced these distinctions.

(2) Tributary streams and ravines, by pouring in detritus, form local enlargements of the terraces of lakes, and usually also of rivers, but the special disposal of the material is different in the two cases. In a lake a delta terrace is formed symmetrically about the entrance of the tributary—subject to the accidents of the situation—the material fanning out equally to the right and to the left and being thrust out in front into the lake by the force of the entering stream. In a river the material thrown in by a tributary is carried down stream and may be entirely borne away. In any active river the formation of the delta is checked on the upper and front sides and its growth directed down stream in a more or less bar-like fashion.

(3) In the lacustrine class, the wave-cut terrace, the sea cliff, and the wave-built terrace are situated together, the material for building the last being derived from the erosion of the others. On the other hand, the river-cut cliff is usually at the convexity of the river bend or at least at some point where it impinges on the adjacent highland; while the correlative river-built terrace is in the concavity of the bend below, or at least in some suitable lodgment spot, invariably down stream.

(4) The material of lake terraces is usually different from that of river terraces. In narrow land-locked lakes very little attrition of shore material is possible, and the terraces either consist of fine material or of little-worn rock fragments. Moreover, the little wearing observed is of the beach order rather than that of stream-rolling. On the other hand, the material of river terraces is stream-rolled and current-assorted alluvium. This distinction fades out in proportion as the river, by the slackness of its stream, approaches stagnant, lake-like conditions.

The foregoing statements have reference to temporary lakes occupying river valleys for a limited time, and so merely developing terraces along their slopes, but not filling up their beds. If the entire bed was filled up, and the terraces, instead of being formed directly by the lake or stream, were carved out by subsequent erosion and the question becomes one of deposition and marginal erosion, and not of terrace formation, some of the above criteria become inapplicable while others gain in force. The evidence from cliffs and rock shelves becomes stronger because in the longer lapse of time involved the differences between the laws of lake-cliff formation and of river-cliff formation more fully expressed themselves.

So, also, the distinction of material becomes more pronounced; for as

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the filling of a lake progresses it retires from the bordering slopes and isolates itself in its own deposits, and the material becomes more and more distinctive and more fully assumes the lacustrine phase of assortment and lacustrine habit of stratification and thus distinguishes itself from fluvial deposits.

These statements of criteria lack both in fullness and in qualification. The distinctions will not always be sustained in a rigid application, under all conditions and in every local instance. Absolute and invariable distinctions will not be expected by experienced students of nature. But these criteria hold good in the main, and in the present instance they are regarded as entirely decisive.

## TERRACES OF THE UPPER OHIO RIVER DISTRICT.

With a view to some preliminary determinations having bearings upon the crust changes, time relations, and drainage conditions of later Tertiary and of Quaternary times, Mr. G. K. Gilbert and myself spent twenty days in the fall of 1885 in a joint reconnaissance of the terraces and related phenomena of the Monongahela, Alleghany, Upper Ohio, and tributary valleys. Mr. Gilbert, as geologist in charge of the Appalachian division of the survey, approached the subject in search of light upon the former attitudes of the surface and possible orographic changes, and brought to the study a large experience and an acknowledged acumen in the analysis and interpretation of fluvial and lacustrine phenomena. My own approach was from the glacial side. Our impressions throughout were in the closest harmony, and I have Mr. Gilbert's assent to the views involved in the following statements:

The terraces of the upper Ohio River district embrace five classes, viz:

1. The high horizontal benches of Stevenson.
2. The upper river terraces.
3. The lower river terraces.
4. The slender horizontal terraces.
5. The structural or differential degradation terraces.

Discussion has previously related chiefly to the second class.

### I. THE HIGH HORIZONTAL TERRACES.

These, so far as I am aware, were first described by Prof. J. J. Stevenson, from the résumé of whose observations[1] the following quotations are taken:

Looking now at the observations recorded in the foregoing part of this paper, we see that, although very fragmentary, they show the existence of two sets of benches, in one of which, the higher, the individuals have an almost unvarying level, whereas

[1] Proc. Am. Philos. Soc., vol. 18, 1880, p. 302, 303. Also Second Geol. Survey, Pennsylvania, KKK (Report of progress in the Fayette and Westmoreland district, Part II, the Ligonier Valley), 1878, p. 260.

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in the other or lower set the members have no definite altitude with respect to tide, but vary much, as do the beds of the streams along which they are found. Arranged in tabular form we have, first, the benches of the higher series:

| | Feet above tide. |
|---|---|
| 1. Chestnut Ridge, Seaton Road | 2,580 |
| 2. Chestnut Ridge, National Road | 2,400 |
| 3. Top bench of Somerset County | 2,323 |
| 4. Middle bench of Somerset County | 2,288 |
| 5. Bottom bench of Somerset County | 2,123 |
| 6. Bench near Confluence | 1,820 |
| 7. Sixth bench near Loyalhanna | 1,690 |
| 8. Fifth bench near Loyalhanna | 1,570 |
| 9. Fourth bench near Loyalhanna | 1,520 |
| 10. Third bench near Loyalhanna, also at Hillsborough and Beallsville | 1,475 |
| 11. National Road, Washington County | 1,445 |
| 12. National Road, Washington County | 1,420 |
| 13. Second Loyalhanna bench, also National Road near Beallsville and Hillsborough | 1,380 |
| 14. National Road east from Brownsville | 1,350 |
| 15. Tenth bench of Stewartstown series | 1,290 |
| 16. Intermediate bench, Dunbar Creek, Possum Creek, Greensburgh | 1,270 |
| 17. Ninth bench of Stewartstown series, First Loyalhanna bench | 1,225 to 1,240 |
| 18. Eighth bench of Stewartstown series | 1,195 |
| 19. Seventh bench of Stewartstown series | 1,130 |
| 20. Sixth bench of Stewartstown series | 1,100 |

The elevation of low water at Pittsburgh, as used by the city surveyor's office, is 699 feet above mean tide. * * *

The variations in level exhibited in individual benches of this series are so slight that they may be due either to petty variations of the barometer, or to errors in reading it, or to the fact that, in every case, the highest point on the bench was sought, so as to determine the top of the detrital deposit. As that deposit, though very thin, has suffered more or less from erosion, one could not, even with perfect instruments, obtain a series of measurements which would tally accurately. The extreme of variation, even in No. 17, where two benches are confounded, is scarcely 18 feet, so that one is fairly justified in regarding the benches as practically horizontal and parallel.

The deposit on these branches sometimes contains a little clay, but sand greatly predominates. No rolled or polished fragments of stone occur, and such fragments as are present belong altogether to rocks found in the immediate vicinity. Nothing shows that running water had ever passed over those plains, so that if the water were in motion its effects must have been confined within a limited space.

Typical portions of these terraces were examined by Mr. Gilbert and myself, but not with sufficient detail nor over a sufficient extent of ground to justify us in publishing any opinion regarding them, especially as it does not concern us here; for, if I have not altogether misunderstood the advocates of the Cincinnati ice-dam, this series of terraces is not included among those ascribed to that agency—indeed, this series has not, I think, even been alluded to in the papers on that subject.

Manifestly there are insuperable objections to such reference, for, in the first place, the lowest of these is higher than the summit of the supposed dam, and, in the second place, the vertical range of the series itself is twice that of the ice obstruction. A series of terraces reaching

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from 1,100 feet to 2,580 feet above tide could not rationally be referred to an ice-dam ranging from 440 feet (low water in the Ohio at Cincinnati) to 950 or 1,000 feet above tide. A dam of 500 feet would scarcely make a series of terraces having a vertical range of 1,430 feet.

### II. THE HIGHER RIVER TERRACES.

These have been described and discussed, either locally or areally, by Prof. J. J. Stevenson,[1] Prof. I. C. White,[2] Prof. J. P. Lesley,[3] Mr. H. Martyn Chance[4] and Prof. G. F. Wright.[5] The whole system has not yet, however, been thoroughly examined, and a complete and entirely satisfactory discussion is not yet possible, but the leading features are determinable. The term "river terraces" was applied to these by Professor Stevenson, and indicates the interpretation which he placed upon them. A similar view was evidently entertained by Mr. Chance for the portion which he has described. In this view we also concur, and hence retain the name. It seems necessary, however, to distinguish these from a lower series of river terraces of separate origin and history. Among the distinguishing characteristics of the higher river terraces are the following:

(1) *They slope with the present streams.*—This tendency is well expressed by Stevenson:

> The river terraces fall down stream and are covered by irregularly bedded sand, clay, or gravel, containing transported fragments, which have been rounded by the action of running water. When followed up the streams these terraces show differences among themselves in degree of slope, so that each is merged successively into the next higher, until that which at the mouth of the stream is the river "bottom" becomes the only terrace, and is lost at last in one of the lower horizontal benches.[6]

In the following table an attempt has been made to collect all observations at command relative to the chief upper terrace of this series on the Monongahela River, and also the uppermost limit of pebbles, as these constitute the most trustworthy and significant data:

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[1] Second Geol. Survey Pennsylvania, K, Green and Washington Dist., 1876, pp. 11–19; KKK (Ligonier Valley), 1878, pp. 251–263; Proc. Am. Philos. Soc., Phila., vol. 18, 1880, pp. 289–316; Am. Jour. Sci., 3d series, vol. 15, 1878, pp. 245–250.

[2] Second Geol. Survey Pennsylvania, Q, Beaver River Dist., 1878, pp. 9–14; also, QQ, 1879, p. 10–12; Proc. Am. Assoc. Adv. Sci., thirty-second (Minneapolis) meeting, 1883, pp. 212, 213, and Science, vol. 2, 1883, pp. 319, 320.

[3] Second Geol. Survey Pennsylvania, Q, 1878, pp. xxiv, xli.

[4] Second Geol. Survey Pennsylvania, VV, Clarion County, 1880, pp. 17–21.

[5] Boston Soc. Nat. Hist., 1887; Am. Naturalist, vol. 18, 1884; Am. Jour. Sci.

[6] Stevenson: Proc. Am. Philos. Soc., vol. 18, 1880, p. 314.

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*Table of observations on the upper pebble-bearing terraces and upper observed limit of pebbles on the Monongahela River, given in descending order.*

| Locality. | Upper pebble-bearing terrace. | | Upper observed limit of pebbles. | | Observer. |
|---|---|---|---|---|---|
| | Above river. | Above tide. | Above river. | Above tide. | |
| | *Feet.* | *Feet.* | *Feet.* | *Feet.* | |
| Morgantown, W. Va | 275 | 1,065 | ..... | ..... | I. C. White. |
| Between State line and Georges Creek | 280 | 1,055 | ..... | ..... | J. J. Stevenson. |
| Greensborough | 275 | 1,050 | ..... | ..... | Do. |
| Mouth of Muddy Creek | 260 | 1,025 | ..... | ..... | Do. |
| Carmichaels (abandoned channel) | 250 | 1,015 | ..... | ..... | White. |
| Pumpkin run | 300 | 1,063 | ..... | ..... | Stevenson. |
| Brownsville (2 miles above) | 230 | 970 | 250 | 990 | Chamberlin. |
| California (1 mile above village) | 180 | 920 | 215 | 955 | Gilbert. |
| Opposite Wood's run (sloping shoulder) | 180 | 920 | 200 | 940 | Gilbert and Chamberlin. |
| Old Troytown | 180 | 920 | 195 | 935 | Do. |
| Fayette City (back of) | 180 | 920 | 200 | 940 | Do. |
| Between Fayette City and Belle Vernon (abandoned channel—oxbow). | 200 | 940 | ..... | ..... | Do. |
| One mile back of Belle Vernon (abandoned channel). | 195 | 935 | 220 | 960 | Chamberlin. |
| Opposite Belle Vernon | 180 | 940 | 185 | 945 | Gilbert. |
| Belle Vernon | 180 | 940 | ..... | ..... | Stevenson. |
| Monongahela Cemetery | 190 | 920 | 200 | 930 | Gilbert and Chamberlin. |
| West Elizabeth | 185 | 905 | 210 | 930 | Do. |
| McKeesport | 190 | 910 | 205 | 925 | Do. |

The grouping of the terraces in this way is not intended as a mode of assertion that they form a single simple series. Under the view that they are river terraces it is by no means necessary to suppose that they are strictly equivalent to one another. On the contrary, it is rather the habit of streams to form different sets of terraces along their course as the result of the unequal resistance of the strata, of the modifying effects of tributaries, and of other agencies which effect unequally the progressive deepening of the river bed. The observations in the Monongahela do, however, seem to show with some degree of force that there is a general equivalence and that the whole series declines, and this is presumably representative of a declining limit of action on the part of the depositing agency. It is not, of course, insisted that the observations are either exhaustive or that the altitudes are strictly accurate, all being barometric determinations.

The tributaries of the Monongahela River bear terraces which are significant, but concerning which the data are more limited. The more applicable of the observations of Profs. Stevenson and White are here cited.

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Respecting Georges Creek, which enters the Monongahela River a few miles north of the West Virginia line, Prof. Stevenson says:[1]

Along this stream the third and fifth benches of the Stewartstown series are persistent, but rise so that at Smithfield the fifth is 304 and the third 200 feet above the river at the mouth of the creek. * * *

Between Smithfield and Uniontown the third, fifth, and sixth benches are seen to be persistent along the east side of Brush Ridge, which marks the course of the Saltsburg axis. But in ascending the creek, the fifth has shown a constant increase in elevation, so that as the divide between Georges and Redstone Creeks is approached, that bench takes the place of the sixth, and finally becomes merged into the seventh.

Of the benches on the Youghiogheny River the same writer says:[2]

At McKeesport the river "bottom" is 765 feet above tide; from that point it is continuous to Connellsville, at the mouth of the Chestnut Ridge Gap, where it is 894 feet above tide.

Opposite Connellsville a fine bench is seen at barely 200 feet above the stream, which is covered by a thick coat of débris containing many huge fragments, all of them having rounded surfaces. The same bench occurs at Perryopolis, where at one time sand was obtained for glass-making.

This terrace rises much more slowly than the river bed above Connellsville, for at Ohiopyle Falls it is barely 140 feet above the river. While this bench was the bed the river flowed directly across the neck of the peninsula at the falls.

The railway elevation of Ohiopyle is given as 1,237 feet above the ocean, but what is the relationship of this to the river or to the terrace is unknown to me. The terrace at Connellsville is 1,066 feet, while the upper limit of pebbles at the mouth of the Alleghany is 925 feet high, showing a very notable fall down-stream.

Prof. I. C. White makes the following statement respecting some of the upper tributaries of the Monongahela River, which seems to conflict with the general tenor of the above data, and which will be referred to in another connection:[3]

The other tributaries of the Monongahela on which the writer has noticed clay and other deposits of the fifth terrace are Decker, Dunker, Whitely, Muddy, and Ten-Mile Creeks, and in each case the deposits disappear at the same absolute level at which they cease along the river.

It may be remarked, however, (1) that the criterion here observed is not rolled pebbles, but clay and other deposits, making it uncertain whether the terraces belong to the system under consideration or to some other; and (2) that these are all small streams contiguous to each other, whose terraces might have approximately the same upper limit under either the fluviatile or lacustrine hypothesis.

Respecting Chartiers Creek, a stream running parallel and contiguous to the Monongahela and emptying into the Ohio, the following statement is made:

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[1] Second Geological Survey, Pennsylvania, KKK, p. 256.

[2] Ibid., p. 259.

[3] Paper read before the American Association for the Advancement of Science, Minneapolis, 1883.

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A terrace continuous along Chartiers Creek from Cook's station to Bridgeville, and on which Grafton station stands, shows the following slope of its level:

| | Feet. |
|---|---|
| Cook's station terrace, above creek at Cook's station | 25 |
| Bridgeville terrace, above creek at Bridgeville | 75 |
| Cook's station terrace, above Creek at Bridgeville | 205 |
| Fall of Chartiers Creek itself | 180 |
| Fall of the terrace level itself | 130 |

This shows that no one of these terraces is by any means on a dead level. These Chartiers Valley terraces continue to its head, and contain limestone drift from the south.[1]

On Montour's Run [a parallel stream running northerly and emptying into the Ohio] a similar terrace is seen, which is even more marked than that on Chartiers Creek. It is traceable along the stream for several miles between Findlay and North Fayette townships of Alleghany County, and falls less rapidly than the bed of the run, the difference being about 35 feet in 4 miles. It shows many rolled and water worn fragments, even so far from the river as Findlay township. Between Robinson and Moon townships of the same county it is much interrupted, and the attempt to determine its relation to the river series was not altogether successful. It seems to be connected with the one occupying the third place in the list already given.[2]

Passing to the Alleghany River, it should be borne in mind that it runs in a course almost directly opposite to that of the Monongahela and associated streams, and is thus extremely well situated for the purpose of the present discrimination, for, on the fluviatile interpretation, its terraces must slope in a contrary direction. The data at command are embraced in the following table:

*Table of observations on the upper pebble-bearing terraces and the upper observed limit of pebbles on the Alleghany River, given in descending order.*

| Locality. | Height of upper pebble-bearing terrace. | | Upper limit of pebbles. | | Observer. |
|---|---|---|---|---|---|
| | Above river. | Above tide. | Above river. | Above tide. | |
| | *Feet.* | *Feet.* | *Feet.* | *Feet.* | |
| Warren | 230 | 1,395 | 250 | 1,415 | Chamberlin. |
| Tidioute | 295 | 1,390 | ..... | ..... | Do. |
| Oil City | 260 | 1,270 | ..... | ..... | Gilbert. |
| Parker | 250 | 1,105 | 275 | 1,230 | Gilbert and Chamberlin. |
| Abandoned channel near Parker | 250 | 1,090 | ..... | ..... | H. M. Chance. |
| Abandoned channel near Parker (col of "oxbow"). | 260 | 1,115 | ..... | ..... | Gilbert and Chamberlin. |
| Bellevue, on the Ohio, 5 miles below Pittsburgh. | 310 | 1,005 | ..... | ..... | I. C. White. |
| Middletown, on the Ohio, 12 miles below Pittsburgh. | 250–280 | 940–970 | ..... | ..... | Wright (this paper). |
| Do | 350 | 1,040 | Occasional pebbles. | | Stevenson. |

[1] Second Geological Survey of Pennsylvania, Q, p. 26.
[2] Ibid., K, 1876, p. 15.

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The two localities on the Ohio River have been added to the Alleghany series because they contain northern drift pebbles in common with the latter. By comparison it will be seen that the fall from the pebble limit at Warren to the pebble-bearing terrace at Tidioute, a distance of 21 miles, is 25 feet, the descent of the present stream being 78 feet. From Tidioute to Oil City, a distance of 35½ miles, the fall is 120 feet, the present descent being 113 feet. From Oil City to the upper pebble limit at Parker, a distance of 49½ miles, the fall is 140 feet, the descent of present stream being 125 feet. From Parker to Bellevue, a distance of 87½ miles, the fall is 125 feet, the present descent being 165 feet.

The foregoing facts, if they justify any conclusion at all, sustain the view that the terraces of the Alleghany River flowing from the north slope southward, while those of the Monongahela flowing from the south slope northward toward their common axis, the Ohio River, precisely as the river terraces do to-day, and at gradients not greatly different.

(2) *The material capping the terraces is distinctly fluvial.* In narrow, winding lakes, such as those must have been which occupied these river valleys if such lakes existed at all, there could have been no great wave force, and consequently no considerable coarse-rolled material, and from the nature of the case, such rounded material as may have been produced must have possessed the well-known characteristics which distinguish lacustrine from fluvially rounded material. But the capping of the Monongahela terraces, and more notably that of the Alleghany terraces, contain large quantities of coarse, well-rolled, and I do not hesitate to say, distinctively river-rolled, material ranging from the finer grades up to bowlders 1 or 2 feet in diameter, and occasionally larger. I measured one 1¾ by 2¾ by 3 feet. Prof. Stevenson records one whose dimensions were 1 by 2 by 4 feet. Both of these were on the Monongahela terraces, where the average coarseness is less than that of the Alleghany terraces. It is true that associated with this coarser rolled material there is much that is finer and indistinguishable from lacustrine material, but that is usually true of fluvial deposits. Such fine material may be said to be an inevitable element of alluvial deposits of low slope, since portions of the river flood must necessarily be relatively stagnant. In the deposits of the great floods of the Ohio at the present day a considerable proportion is of the fine, silty, quasi-lacustrine character.

There are also associated with these terraces deposits of stony clay, not very far removed in kind from the stony clays of the glacial drift, save that the embedded stones are not glaciated. This formation is susceptible of misinterpretation, but its true analogue may be seen in the banks of the present Monongahela, throughout the lower half of its course. The material there is very largely composed of a stony clay concerning whose origin there is no room for doubt. The overflows of the flood season bear out upon the submerged flats chiefly silt, but ice, stumps

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of trees, and other buoyant material bear occasional stones, which are deposited with the accumulating fine material, forming a stony clay or loam. This is not at all an unusual or phenomenal deposit, but on the contrary is a typical form of flood deposit in streams of low gradient, especially in the higher latitudes, where the aid of river ice is annually afforded.

(3) *These terraces are rock platforms.* The chief terraces are rock-cut, and, as stated by Stevenson—

> At every locality where an exposure occurs it was seen that the terrace is merely a shelf worn out of the stratified rock, on which the river has spread a thin layer of detritus. From the bottom of this layer to the next shelf below there is rocky escarpment, never one of detritus.[1]

It would be a misinterpretation to infer from this language that there are continuous rock shelves cut along the whole face of the bluff; they are precisely the opposite of this, being broad platforms of rock at certain points and entirely absent at others. These platforms are not infrequently from a quarter to a half mile or more in width. To have cut these back by the simple wave-action of a narrow, land-locked, hill-sheltered lake would have required a lapse of time which I must leave the reader to estimate for himself. To my own mind, such a work under the conditions of this case is simply impossible, since the excavated material, together with the concurrent inwash from the surrounding country, must have completely silted the lake up before such an amount of erosion, or anything approximate to it, could have taken place.

(4) *The form and distribution of the terraces is of the fluvial, not lacustrine, order.* The distinction between lacustrine and fluvial terraces in respect to form and distribution was indicated in the statement of general criteria. In the last paragraph this feature was incidentally touched upon. The rock shelves, instead of lining the hillsides throughout, and being broader opposite the longer and more forceful sweep of waves, as they should have been had they been produced by a temporary lake, usually have their greatest development in bends of the stream, or in similar dynamic situations, where they have escaped subsequent erosion. It appears to us perfectly clear from an inspection of the ground that the chief of these platforms are but portions of the bottoms of the ancient river which were left in the subsequent cutting down of the channel. The most convincing evidence of this will appear under the following heading, but such broad platforms as occur at Brownsville, Yorkville, Bellevue, New Brighton, and elsewhere, with their rock bases and their rock faces, appear to us to admit of no other interpretation.

(5) *Abandoned channels—"oxbows."* But the most specific evidence of this is found in the abandoned loops of the ancient river, which, after their necks had been cut across by the stream, were left as irrefutable evidences of the status of the streams at the time they were

[1]Second Geological Survey, Pennsylvania, K, 1876, p. 17.

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formed. An excellent description of one of these, near Parker, on the Alleghany River, has been given by Dr. H. M. Chance,[1] as follows:

In driving east from Parker along the road leading to West Freedom, a strikingly broad and open valley is seen, and in it a small, sluggish stream, entirely disproportionate in size to the breadth of the valley.

At Hagerstown the wagon-road crosses this valley, which here bears off to the northeast, but bending around to the southeast it is again crossed by the road one mile from West Freedom.

Leaving the main road and following the valley for half a mile toward the southeast a summit is reached, on the south side of which another stream heads and flows * * * through a valley similar to the first. The divide is in swampy ground.

At Perryville the north side of the valley is steep and the south side of more gentle contour, but at Hagerstown the reverse is seen, while throughout the back of the bend, on either side of the summit, the inside of the loop presents gentle slopes facing the more precipitous rock-covered declivities surrounding its outer border.

The summit of this old valley is about 1,090 feet above ocean level, or 250 feet, more or less, above low water in the Alleghany River at Parker. It has been cut down into—if not entirely through—the Homewood sandstone, which outcrops in the valley wherever the side slopes are steep enough to expose it.

The valley is filled throughout by a deposit of river silt containing a small percentage of glacial drift, evidently reworked and redeposited by fluviatile action. This silt consists of sand, gravel, and clay beds irregularly, though truly stratified—the counterpart of the silt found along the present channel of the Alleghany River. The coarser gravel beds in which water-worn fragments of the Coal Measure and conglomerate rocks largely predominate, are sometimes consolidated by a calcareous cement, thus being converted into recent conglomerates, similar to those seen along Oil Creek Valley.

A short distance below Hagerstown the stream cuts through the drift into the subjacent rocks, through which its descent is very rapid to the Alleghany River near Parker. The same feature is noticeable on the opposite side of the loop, where the stream cuts through the drift near the Monterey road-crossing.

The almond-shaped hill inclosed by this valley and the Alleghany Valley rises nearly one hundred and fifty feet above the drift deposit. It contains the ferriferous lime-stone and its underlying coal-beds.

A magnificent view of both sides of the valley and the included island may be obtained from the summit of the road leading to West Freedom, at a point one-half mile west from that town.

That this old valley was once part of the Alleghany or Clarion River channel can not be doubted. It evidently formed an oblong loop or bend that was probably cut through by an excessive undercutting erosion on the two opposite sides of the neck or narrowest part of the loop, just as the river is now slowly eating its way through the neck of Brady's Bend. This action may have been facilitated by the ice riding over the neck of the loop.

As soon as the river found a vent through the loop the old channel was abandoned; but during high water, and before the river had appreciably lowered its level, this old bend must have been a back channel, with more sluggish current than the new cut. Under these conditions it was probably filled with the drift it now contains.

But the present level of the Alleghany and Clarion Rivers is at least two hundred feet beneath bed-rock in the old channel, and as the river is now flowing on a false bottom fifty feet, more or less, above the true bottom of the valley, it is evident that the old channel is two hundred and fifty feet above the true bottom of the Alleghany River at Parker; or, in other words, the Alleghany River has eroded a valley two hundred and fifty feet deep, and subsequently refilled it to a depth of fifty feet since the old channel was abandoned by the main stream.

[1] Second Geological Survey, Pennsylvania, VV, 1880, pp. 17–20.

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As the silt filling the abandoned water-course contains some glacial drift—pebbles worn from the Eozoic rocks of Canada—it follows that the river did not entirely abandon this channel until the commencement of, or some time subsequent to, the glacial period. The river, then, must have accomplished the erosion of this deep gorge and a partial refilling of it since the commencement of the glacial epoch, or possibly in less time.

The observations of Mr. Gilbert and myself support those of Mr. Chance in all essential particulars. Above the ancient channel the hills rise by relatively gentle, well graduated slopes, indicative of protracted erosion of the whole surrounding country, while the valleys below this horizon, with scarcely an exception, present steep declivities and often vertical rock cliffs, indicating rapid and relatively short erosion. In other words, the topographic contours above and below this horizon stand in sharp contrast, and of themselves indicate diverse histories.

The similar abandoned channel between Fayette City and Belle Vernon, on the Monongahela, presents almost identical characteristics. At Fayette City, where the present channel diverges from the ancient one, a rock face appears in the cross-section of the latter, and again at Belle Vernon, where the old channel is crossed by the new, there are steep rock faces on both sides, showing conclusively that the old channel is rock-bottomed. Besides these evidences, in themselves conclusive, the creeks that flow in the abandoned channel cut down through the alluvium into the rock along considerable stretches in the lower portions of their courses. The bed material of this old channel seemed to us to be clearly fluviatile, and not lacustrine. Among this material are rounded masses, one, two, and even three or four feet in diameter.

As in the preceding case, from this old river bottom the hills rise by harmonious, well-graduated erosion slopes to the adjacent summits, 200 or 300 feet above, while below this horizon the slopes descend with steep declivities, and often precipitous faces. The plain of this abandoned channel is a horizon of demarkation between long continued general erosion above, and relatively rapid vertical cutting below. The ox-bow at Carmichael's we did not see, but from the description of Profs. White and Wright there seems no ground to doubt that it is in every way similar in character. So, also, doubtless, is Teazes Valley.

To us these are clear and unequivocal instances of abandoned river valleys, and their testimony respecting the origin of the terrace plains, of which they are the largest and best preserved remnants, is of the most unequivocal and decisive character. The fragmentary terraces left by the erosion of the stream along its general course, where it has followed approximately its ancient route, are but minor portions of a continuous river bottom, or of a series of river bottoms, formed during the progressive cutting down of the rivers.

It seems highly probable that these abandoned loops at Carmichael's, Belle Vernon, and Parker are to be correlated together and to be connected with the broader, more deeply covered rock terraces that line

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the Monongahela, Alleghany, and upper Ohio Rivers, for in each of these instances there lies upon the ancient rock bottom a bed of fluvial material ranging up to 40 or 50 feet in thickness, and from these terraces there likewise spring the characteristic curves of ancient erosion sweeping over the uplands, while equally characteristic slopes or cliffs of rapid erosion lead down to the present river bottoms. The occurrence of subsidiary terraces does not essentially modify the truth of this generalization.

### III.—THE LOWER RIVER (OR MORAINE-HEADED) TERRACES.

The third group of terraces are sharply distinguishable from those which have just been considered, first, in the fact that, instead of being rock platforms covered by fluvial material, they are made up bodily of coarse alluvium, mainly gravel. They have their chief development in the rivers entering the Ohio from the north, and when traced up they are found to head on one of the moraines of the later glacial epoch, or at least of a later glacial epoch following at a considerable interval an earlier one. The uppermost of these terraces has for its surface plane the ancient flood deposits of the glacier-fed streams. The lower terraces have been cut out of it by subsequent erosion. Near the moraine this upper glacial flood surface may be traced continuously, rising somewhat rapidly as the moraine is approached, and passing gradually into a series of undulations which merge into the gravelly knobs and basins, and thence into the unassorted hills of the moraine. This relationship was satisfactorily observed by Mr. Gilbert and myself, separately or jointly, on Conowango Creek, near Russellburg; on the Little Broken Straw, near Freehold; on the Big Broken Straw, near Horn's Siding; and on Oil Creek, near Hydetown. On Sugar Creek, French Creek, and Sandy Creek phenomena of similar significance appear, but they are less clear in their import. On Beaver River and Little Beaver Creek analogous features are more satisfactorily displayed.

The streams of gravel starting in these morainic heads run down through the rock channels cut below the old river bottom as above described. The surfaces of these later glacial gravel streams are generally much below that of the earlier terrace deposits, but as they slope more rapidly there is no constant difference. An interval of from 100 feet to 200 feet may be taken as representative. These later glacial gravels extend below the present river beds, reaching depths varying from 40 feet to 250 feet or more, showing a considerable depth of channel before this late filling. These terraces reach their greatest height above the present stream, so far as observed, at the junction of the Beaver River with the Ohio. There the terrace rises 127 feet above the Ohio, according to a lock-level measurement by Mr. Gilbert.

Similar moraine-headed terraces occur in Ohio on the Muskingum, Scioto, and Mad Rivers and their tributaries, and seem to have their

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equivalents in terraces on the lower stretches of these rivers and on the Ohio. In other words, there is a general system of deep valley gravels, starting from the moraines indicated and sweeping down the valleys, growing progressively finer in material. Out of these glacial flood deposits a system of terraces has been cut by subsequent erosion. The still later glacial episodes seem to have introduced modifying elements, but these are unimportant in this connection.

*General remarks on the two systems of river terraces.*—The time and manner of origin of the moraine-headed terrace plains are placed beyond question by their morainic connections. They are clearly the products of the streams that issued from the glacier during the moraine-forming epoch. The carving of the terraces out of these plains was chiefly a subsequent work, of relatively minor importance in the present discussion. The coarseness of the gravels of this series indicates vigorous drainage, which in turn implies an open valley and at least a fair gradient below. It is equally evident that terraces of a much higher level and different gradient could not have been formed at the same time. Minor side-valley terraces might have been formed at flood stages, but only to the height of the maximum floods, and these must have had the same slope as the broad flood plains.

It is clear that the upper gravel-bearing terraces were not formed at the same stage as these moraine-appended ones, for they are not only of a different type, being alluvium-covered rock platforms, but they stand high above most of the morainic heads of the later deposits and show much greater antiquity in the erosion of their surfaces. For example, at Warren the old gravels have an altitude of 1415 feet above sea-level, with a terrace at 1395 feet, while the moraine-headed flood deposits of the later epoch at Russellburg, eight miles upstream, occur at about 1275 feet. On the Beaver River the moraine-headed gravel stream has an elevation of about 830 feet, while along the valley below pebbles referred to the earlier epoch range from 900 to 950 feet, and ten miles below there is a wide rock-based terrace at about 885 feet. But these higher gravels contain pebbles of granite and other crystalline rock, whose presence is only to be accounted for through glacial agencies, and the explanation of their origin must embrace that element. It is not far to seek.

Outside of the moraine with which the lower series connects itself there lies a tract of attenuated drift, consisting of scarcely more than scattered bowlders,[1] dispersed indifferently over the highlands or

[1] I. C. White: Second Geol. Survey, Pennsylvania, Q, 1878, p. 10; QQ, 1879, p. 9, and QQQ, 1880, pp. 15-17.

T. C. Chamberlin: "The bearing of some recent determinations on the correlation of eastern and western moraines." Am. Jour. Sci., August, 1882, p. 96.

H. C. Lewis: Second Geol. Survey, Pennsylvania, Z, 1884, pp. 45, 71, 170, 171, 177, 179, 180, 186, 195, 200-202.

G. F. Wright: The glacial boundary in Ohio, Indiana, and Kentucky, tract No. 40, Western Reserve Hist. Soc., 1884, pp. 227, 228.



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gathered in colonies. In the passing allusion cited below, I expressed doubt whether this extra-morainic drift, was an appendage of the moraine or an older drift, here barely emerging from beneath a later one, but which, farther west, extends far out beyond it. Subsequent studies over a wide extent of territory convince me that the latter is the truth. The evidence of this, even in western Pennsylvania, is of itself somewhat strong, but can not be discussed at length here.

Mr. J. F. Carll has presented convincing evidence that the drainage of the present upper Alleghany Basin was toward the Erie Basin in preglacial times, and that it was turned into its present course during the ice invasion.[1] Mr. Carll rested his admirable discussion with the establishment of the general proposition respecting drainage reversal, without attempting to distinguish between the episodes of the invasion. But the facts above cited show that this reversal must have taken place much anterior to the formation of the outer moraine, for the floods of that date poured down through a canyon already cut from 40 to 100 feet below the present river-bottom with the result of partially filling it with glacial gravel, as shown by the following table taken from Mr. Carll's report.

*Table showing altitude above ocean level of the ancient floor of the Alleghany River.*[2]

| Locality. | Railroad levels. | Depth of drift. | Ancient floor. |
|---|---|---|---|
| | *Feet.* | *Feet.* | *Feet.* |
| Warren, Warren County, Pa | 1,200 | 100 | 1,100 |
| Irvineton, Warren County, Pa | 1,168 | 60 | 1,108 |
| Tidioute, Warren County, Pa | 1,113 | 50 | 1,063 |
| West Hickory, Venango County, Pa | 1,092 | 45 | 1,047 |
| Tionesta, Forest County, Pa | 1,060 | 50 | 1,010 |
| President, Venango County, Pa | 1,048 | 40 | 1,008 |
| Henry's Bend, Venango County, Pa | 1,035 | 45 | 990 |
| Oleopolis, Venango County, Pa | 1,032 | 45 | 987 |
| Walnut Bend, Venango County, Pa | 1,023 | 40 | 983 |
| Rockwood, Venango County, Pa | 1,016 | 50 | 966 |
| Oil City, Venango County, Pa | 1,008 | 50 | 958 |
| Franklin, Venango County, Pa | 988 | 40 | 948 |
| Cochran, Venango County, Pa | 982 | 40 | 942 |
| Fosters, Venango County, Pa | 970 | 40 | 930 |
| Scrubgrass, Venango County, Pa | 945 | 40 | 905 |
| Emlenton, Venango County, Pa | 905 | 45 | 860 |
| Parker, Armstrong County, Pa | 889 | 50 | 839 |

Combining these with preceding data, three fluvial planes are to be noted: (1) the rock floor, which, lying 1,100 feet above the sea at Warren, declines southward, as shown in the above table; (2) the moraine-headed terrace plane which starts at Russellburg, eight miles above War-

[1] Second Geol. Survey, Pennsylvania, Report III, 1880, pp. 330-355.
[2] Ibid., p. 337.

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ren, at about 1,275 feet, and apparently about 250 feet above rock bottom, and likewise declines southward; and (3) the upper erratic-bearing terrace plane, which, starting at Warren at 1,395 to 1,415 feet, and having at Tidioute, near the ancient divide, an altitude of 1,390 feet, declines to 1,115 feet at Parkers. The time sequence of these three planes is clear. The high terraces must have been first formed as shown by Mr. Chance. The rock channel, whose bottom represents the cessation of excavation, was eroded after the high terraces were formed and before the later gravels were poured into it. The moraine-attached gravel planes were manifestly last in formation.

The higher glacial gravels antedated those of the moraine-forming epoch by the measure of the erosion of the channel through the old drift and the rock, whose mean depth here is about 300 feet, of which, perhaps, 250 feet may be said to be rock. The excavation that intervened between the two epochs in other portions of the Alleghany, Monongahela, and Upper Ohio Valleys is closely comparable with this.

In view of these facts it seems scarcely less than proven that it was the earlier invasion of ice that reversed the drainage and partially filled the valleys with débris, forming the capping of glacial gravel that rests upon the upper terraces.

As we read the history of events, the salient features were as follows: The erosion of the valleys proceeded with relative slowness during the stages immediately antedating the time at which the streams reached the base plane represented by the bottoms of the abandoned channels on the Alleghany and Monongahela Rivers, and the degradation of the surrounding country was relatively great as compared with the downward cutting of the streams. This became more and more pronounced until the streams (in these portions of their channels) reached base planes of erosion, after which they began to build up their bottoms by the fluvial deposits of which we now find remnants. This proceeded until forty feet or more of basal debris was accumulated. This building up of the bottoms of the streams while the degradation of the surrounding country was still in slow progress, afforded exceptionally favorable conditions for changes in the courses of the streams. The two-fold process was especially adapted to bring low necks within the limits of overflow at flood stages, or to cause the disseverance of narrow necks by lateral corrasion. It does not surprise us, therefore, that several important changes took place nearly coincidently during the prevalence of these conditions.

From the fact that the fluvial material in these abandoned channels and on the corresponding terraces in the Monongahela Valley is wholly local, or southern, while among the analogous material of the Alleghany there mingle crystalline erratics of Canadian derivation, and from the evidence given above, we draw the inference that the partial filling was coincident with some stage of the earlier glaciation, presumably a late stage. This view gathers some support from the now well

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sustained belief that a general depression and slackening of drainage accompanied the earlier glaciation.

Following this episode of valley-filling and earlier glaciation there was a prolonged epoch of rapid erosion of the valley bottom, which was apparently coincident with an interglacial epoch, and was, perhaps, the result of the resilience of the land after the glacial depression. During this epoch the rock gorges were cut down to the rock bottoms that now lie forty feet or more below the present river bottoms. Then came the later invasion that halted at the outer terminal moraine, whose overloaded floods, like those of the preceding glacial incursion, filled the valley bottoms with glacial alluvium; only, in this instance, in harmony with the more vigorous character of the later glaciation, the filling reached, at some points, 300 feet. Since that time there has been another stage of reexcavation, giving origin to the lower gravel terraces.

This is doubtless far from being the whole history of events, and may be divergent from the truth in minor phases, but I believe with some confidence that it represents the general truth respecting the history of the abandoned channels and chief terrace deposits of the system of benches under consideration. Were not this introduction already almost inexcusably long, I should desire to give expression to my belief in some minor episodes and to qualify these bald outlines.

Recurring to the question of the relationship of these terraces to the supposed ice dam at Cincinnati, it becomes obvious that, if the foregoing identifications are correct, the phenomena do not admit of explanation by such an obstruction. In a different way they find their elucidation in the conditions that accompanied the ice invasions. That there were at least two incursions of ice, that both had the habit of filling up the bordering valleys with their drainage matter, that a depressed condition of the land and a slackened drainage were coincident with certain stages of each, and that there was a prolonged interglacial interval of erosion, are indicated by a wide range of phenomena. In support of the lower gradient of the streams, which is the leading feature of the explanation of the much-discussed higher river terraces, there may be cited, on the one side, the extensive deposits of the loess on the lower Ohio, the Wabash, the Illinois, the Mississippi, and the Missouri Rivers, as shown by the concurrent observations of numerous geologists, and, on the other side, the yellow gravels and the brick clays of Philadelphia, the bowldery deposits about the Delaware and Chesapeake Bays, and the Columbia formation of the Potomac and adjacent regions, as worked out respectively by Messrs. H. C. Lewis, F. D. Chester, and W. J. McGee.

So, also, in confirmation of the very considerable erosion which took place between the invasions, there is, on the one hand, the great erosion of the Missouri Valley from the Great Falls, in Montana, to southern Dakota, in the course of which, for long stretches, it has manifestly cut

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its entire channel of from three hundred to eight hundred feet in depth since the early drift epoch, and, on the other hand, the erosion of the Atlantic streams, notably that of the Potomac, where the entire gorge from below the Great Falls has been excavated in obdurate crystalline rock since the earlier glacial epoch, as shown by McGee.

In short, both in the great interior basin, on the one side, and on the Atlantic coast on the other, as shown by independent observations, there appear to have been prevalent the two great features of which we find additional evidence in the terraces of the upper Ohio and its tributaries, viz: first, a general depression coincident with the earlier ice invasion, and, second, a prolonged interval between invasions, marked by greater erosion.

Respecting the argument of Prof. Wright, that the high state of preservation of the vegetal deposits indicates a recency incompatible with the great lapse of time which the erosion of the valleys implies, I have only to remark that I know of no criterion by which the minimum rate of decay or lithification of vegetal deposits takes place when the material is buried in clay or constantly submerged by ground-water. The whole tenor of the study of fossil remains is to emphasize the fact that the preservation has been extraordinarily perfect under certain conditions, while under others the completeness of the destruction has been equally phenomenal. It appears to me that the rate of decay and of lithification of buried vegetal material is a problem rather than a proof. Very fresh-looking wood is found in the *Tertiary* deposits of the lower Mississippi Valley.

### IV. THE SLENDER HORIZONTAL TERRACES.

A system of slender terraces, lying along the slopes of the hills back of Wheeling, W. Va., has been observed by Mr. W. J. McGee, of the U. S. Geological Survey. With them he is inclined to correlate some of the terraces of the Monongahela River and some of its tributaries, which have been examined by him. These terraces are far from being constant, and commonly occur only at localities obviously favorable for their formation and preservation. There are usually two, but rarely three or more members, all within a vertical interval seldom exceeding fifty feet. They differ entirely from the preceding classes, being merely slender bands of slope-wash lodged along the sides of the hills, reaching a thickness of perhaps ten feet, measured normal to the hill slope, and having sloping surfaces. So far as observed they maintain a horizontal position. They seem to be just such accumulations as might gather on the margin of a ponded stream in a comparatively limited interval of time. The mean altitude, on both the Ohio and the Monongahela, is about one hundred and fifty feet.

As indicated in a quotation made above, Prof. I. C. White finds on several of the tributaries of the Monongahela clayey terrace deposits, which disappear at the same absolute level at which they cease along

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the main river. It may be that these clayey terraces constitute a horizontal system equivalent to those observed by Mr. McGee, while the rock benches and alluvium-capped terraces of the region belong to the ancient river system, and that in this discrimination lies the reconciliation of seemingly inharmonious observations. The data at command are far too limited to warrant a confident conclusion. These observations should stimulate a further search for this class of terraces, and in this search it is supremely important that these slender, slope-wash terraces should be distinguished from those which have heretofore been the chief, if not the exclusive subjects of discussion in this region, and with which they have little in common beyond the bald fact of being terraces.

### V.—THE STRUCTURAL TERRACES.

The fifth series of terraces which mark the slopes of the upper Ohio and its tributaries are obviously structural or degradational, being dependent upon the unequal resistance of the paleozoic strata that form the hill-slopes of the river valley. They are horizontal where the strata lie horizontally and inclined where the strata lie inclined. Their origin is obvious.

### SUMMATION.

Summing up the subject of the terraces, it is to be remarked (1) that the highest series of terraces are horizontal, but have elevations the lowest of which is above the reach of the supposed Cincinnati ice-dam, and the range of which, according to Prof. Stevenson (on whose observation the determination of the whole series rests), greatly exceeded the total range of the ice-dam, and that the two, for other and obvious reasons, can have no causal relationship; (2) that the upper series of pebble-bearing terraces carry evidences that to us are clear and decisive that they are fluviatile in origin and that they were contemporaneous with the earlier glacial epoch; (3) that the lower series of gravel terraces are demonstrably connected in origin and in time with a later ice incursion, during which was formed the outer moraine which has been so carefully traced by Profs. Lewis and Wright across northern Pennsylvania; (4) that the slender horizontal terraces observed by McGee (and perhaps certain portions of those observed earlier by Prof. White, but not separated in discrimination from the fluvial terraces), may be the relics of the work done by the waters ponded by the glacial obstruction at Cincinnati; but too little is yet known of these to justify more than this suggestion; and (5) that the structural terraces are evidently due to differential degradation and have obviously no relationship to the question under discussion.

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# THE GLACIAL BOUNDARY IN WESTERN PENNSYLVANIA, OHIO, KENTUCKY, INDIANA; AND ILLINOIS.

By George Frederick Wright.

## INTRODUCTION.

The following is a preliminary report of progress concerning my investigations relating to the glacial boundary in western Pennsylvania, Ohio, Kentucky, Indiana, and Illinois. But as, according to instructions, the work is supplementary to what had already been done in the same field, it has been necessary to give a summary statement of facts previously discovered and published.

The main problem has been to determine by actual observation the exact southern line along which the signs of the so-called direct glacial action cease to be apparent. To accomplish this it has been necessary to examine personally a belt of territory along the whole distance sufficiently wide to demonstrate that the phenomena denominated "glacial" actually exist down to the line, and that they do not exist south of the line.

The phenomena chiefly relied upon as proofs of direct glacial action are the existence of striated surfaces of rocks in place, the occurrence of the unstratified deposits called "till," and the discovery of transported bowlders in such positions as to preclude their deposit by water action. The sufficiency of this proof can be evident only from the report itself. As there may be occasion to question the character of the deposits called "till," I have inserted in the text cuts from photographs of several fresh perpendicular exposures in different places.

## STRIATED SURFACES OF ROCKS IN PLACE.

There is no question that an exposed surface of rock might be striated by the action of a vast mass of floating ice in shallow water. Icebergs whose lower surfaces barely graze the rock beneath, and which are moved along by strong and steady currents of water, might produce striæ which are in a general way parallel with each other over extended surfaces of level country. But that the striation char-



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acterizing the greater part of the drift-covered portion of North America could not have been produced by floating ice is evident from a variety of considerations.

In the first place, striated surfaces are found in situations where it is impossible to suppose there could have been any currents of water in which ice could float; and the striæ in these places correspond in all respects with those ordinarily found in other situations. For example, limiting myself to observations of my own, in Davidson township, Sullivan County, Pennsylvania, there are numerous and well-defined striæ upon the exposed surfaces of Pocono sandstone, lacking only a few hundred feet of being as high as the highest summit of the Alleghany Mountains, and not far from 2,000 feet above the sea. The direction of the striæ is here S. 9° W.

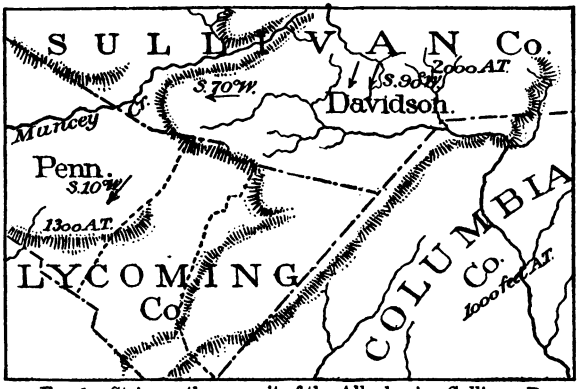


FIG. 1.—Striæ on the summit of the Alleghanies, Sullivan, Pa.

A few miles west in the valley of Muncy Creek, there are other striæ at a lower level, whose direction is evidently determined by that of the valley which bears in some places S. 70° W. At a still lower level, and farther down the creek after it emerges from the Alleghany escarpment (which here, as elsewhere, bears from NE. to SW.), in Penn township, Lycoming County, the striæ turn again to a more southerly direction, bearing S. from 10° to 20° W. There is here no chance for a current of water moving over the Alleghanies to produce all these striæ; for every appearance indicates that they were contemporaneous, and water which would barely suffer the ice to graze the surface in Davidson township, Sullivan County, would be too deep in Penn township, Lycoming County, to allow a floating body of ice to graze the surface there, which is at least 700 feet lower than the other in Davidson township. Nor would there be any opportunity for a current of water to set over Penn township from the north, since the escarpment of the Alleghany is only two or three miles distant in that direction, and it is in all places from 700 to 1,000 feet above it.

Nor could this striation be the result of a local glacier, since Davidson township has no higher land to the north in which a local glacier

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could form. On the other hand, everything coincides with the supposition that a continental ice-movement from the north here surmounted the Alleghanies, and that its force was nearly spent at this point. The striæ on the unobstructed surface of Davidson township represent the normal movement of the ice in that vicinity, while the variations in direction down Muncy Creek show the disturbing influence of a local valley near the margin, down which the semi-fluid mass would press in obedience to its laws of motion.

This is but an instance of what may be found in various other places in the mountain regions of Pennsylvania.[1]

Phenomena similar to these just described are also not infrequent northward, making it evident that the striæ now exposed to observation were those produced by the last movements of the ice near its margin and during its period of final retrocession. Each forward movement of the ice, like that of a plane or rasp, would obliterate the marks of the previous movement.

In the region coming more immediately within the limits of the present report, namely, that lying west of the Alleghanies and extending to the Mississippi River, the observed striæ near what I have taken to be the limit of direct glacial action have been comparatively rare; still they are sufficient to illustrate the same general principle. In the places where these marginal striæ have been observed there is usually either a barrier which would obstruct the progress of a current of water flowing in the direction of the striæ, or, where there is no barrier, there is such a sudden cessation of glacial deposits as could not have occurred if the transporting agency had been floating ice. The water deep enough to have floated bergs to the locality of these striæ, and to the limit of glacial deposits not far beyond, would, in the absence of barriers, have transported this glacial débris still farther south.

Again it is noticeable that these marginal striæ very uniformly point at right angles to the marginal line itself in the locality where they occur, so that in repeated instances I was able from the direction of the striæ to prophesy the direction of the nearest point in the margin of the glaciated area.

For example, the striæ in Mercer and Lawrence Counties, in western Pennsylvania, have a general direction S. 45° E., which is very nearly at right angles to the line marking the limit of direct glacial action a few miles away.[2]

Again, in Highland County, Ohio, the average bearing of striæ is S. 26° E., at right angles again to the glacial margin a few miles away.

At Woodsdale, Butler County, Ohio, about 20 miles north of Cincinnati, well defined striæ occur, running nearly N. and S. These are of

[1] For further particulars respecting other places in Pennsylvania see Second Geol. Survey, Pennsylvania, Z, containing the report of H. Carvill Lewis and myself upon the terminal moraine in that State, especially the reports on Monroe, Luzerne, Columbia, and Lycoming Counties.

[2] Op. cit., p. 189.

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additional interest as showing the degree to which the ice movement at this point was independent of the local topography. The striæ here observed were upon the south side of the Miami River (whose general course is here NE. and SW.), and 75 feet above low-water mark. The direction of the striæ is diagonal to that of the valley, which is here a mile or more in width, but nearly at right angles to the general course of the glacial boundary, about 20 miles to the south.

Near Vandalia, Owen County, Ind., well marked striæ appear running from S. 40° to 50° E., some bearing still more to the east. Here, again, the limit of direct glacial action (which is but a few miles away), after having swung from Clark County, near the Falls of the Ohio, at Louisville, Ky., to the north as far as Morgan County, is now for a long distance passing in a SSW. direction toward Posey County.

The point farthest south at which striæ have been observed east of the Mississippi is near the southwest corner of Williamson County, Ill., about latitude 37° 35′.

This is near the apex of a great southern loop in the glacial boundary, which extends but a few miles farther to the south; and the direction of the eastern set of striæ, in Williamson County, is S. from 10° to 15° E., while that of the western set, about 12 miles distant, in Jackson County, is S. 5° W. The striæ are here undeniable and most clearly marked

## SUMMARY OF FACTS CONCERNING THE UNSTRATIFIED DEPOSIT CALLED TILL.

### PRELIMINARY REMARKS.

Full descriptions of till and its associated deposits are given by President T. C. Chamberlin in his preliminary paper on the Terminal Moraine of the Second Glacial Epoch.[1]

It is sufficient here to remark, in general, that the agency through which the drift deposits are supposed to have been distributed is one which is capable of producing very complicated results. During the whole existence of the continental glacier, especially at certain seasons of the year, there must have been connected with it a great amount of water action; and through the agency of the enveloping sheet of glacial ice, water must have been set free in places and under conditions very different from those in which it would be a modifying agent after the ice had withdrawn. In all those valleys whose natural drainage is to the north there would be a period, both during the advance and during the retreat of the ice, when temporary lakes would exist in its front. In all such places, of course, there would be opportunity for that peculiar stratification of the material characterizing the deposits distributed by water. It is easy to see that these conditions would exist to a marked degree in Ohio north of the water-shed.

[1] Third Annual Report U. S. Geol. Survey, 1883, pp. 295–310.

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On the other hand, south of the water-shed, where the main drainage lines were always open to the south, it would be rare that any large confined body of water could have existed for any great length of time. But wherever there was an ice front at any level there must have been, especially during the period of retreat and during the summer months, a vast amount of water set free even upon the high lands, which in its impetuous course would sort the material and deposit terraces and deltas of sand, gravel, and pebbles in positions that are quite impossible in the present condition of things. My observations have been particularly directed to the effects of this complicated agency south of the water-shed between the Ohio and the lakes, and more particularly near the southern margin of the region over which the marks of the direct action of glacial ice are unmistakable. In conducting these observations I have incidentally traversed nearly the whole region between the lakes and the Ohio in every direction, and have carefully zigzagged the whole marginal line from the Alleghanies to the Mississippi, crossing and re-crossing it at short intervals (usually from one to two miles), extending my observations over a considerable belt of the territory beyond the limit assigned by me to direct glacial action. An incidental branch of the investigation, and one which in interest and importance is so great that it well-nigh overshadows the main inquiry, pertains to the effects during and towards the close of the glacial period of water action along the valleys opening to the south, and which lie for the most part outside the glaciated region. With a remarkable uniformity these valleys contain immense deposits of gravel, which line their sides to a level far above the reach of present streams.

## GENERAL DISTRIBUTION OF TILL AND ITS RELATION TO BURIED CHANNELS.

The distribution of drift material over the glaciated region south of the water-shed between the lakes and the Ohio is more uniform than it might seem to a local observer. As Prof. J. S. Newberry[1] long ago pointed out, glacial action in Ohio was superinduced upon a country whose minor topography had been shaped by the long-continued erosive action of running water. These preglacial streams had everywhere eroded channels through the sedimentary rocks hundreds of feet in depth, and south of the glaciated limit these channels are still the marked feature of the country.

North of the line the channels have ordinarily been filled with till so as completely to obliterate them. According to Prof. Newberry the Cuyahoga River (flowing north and emptying into Lake Erie at Cleveland) occupied in preglacial times a bed 200 feet beneath its present bottom, since borings along its bed for twenty miles above its mouth penetrate that depth before reaching the rock, while the rocky escarpment on each side of its present narrow valley now rises from 200 to

[1] Report Geol. Survey, Ohio, vol. 1, pp. 34, 37, 44, 172, 175, 177, 205, 418, 433, 461

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300 feet above it. Previous to the glacial period this river must therefore have occupied a narrow trough from 400 to 500 feet deep. Prof. Newberry had also called attention to a buried channel occupied in preglacial times by Rocky River (a stream emptying into Lake Erie a few miles west of the Cuyahoga), but which was filled up by glacial débris, so as to compel the stream to seek another channel in the lower part of its course. Recently Dr. Gould, of Berea, Ohio, has traced this buried channel a distance of more than twenty miles, connecting it with the wide, deep valley still occupied by the stream in Medina County. The course of the buried channel is traced partly by gathering a record of wells which fail to reach a rocky bottom for 50 or 100 feet below the ordinary depth, but more especially by noting the repeated places at which the present stream in its winding course crosses and recrosses the old valley. Where this occurs the present stream flows between rocky banks both above and below the line of the buried valley, and has a rocky bottom; but in the short space occupied by the old valley itself the stream now flows between banks of till nearly 100 feet high, and has a muddy bottom.

Thus, in the main, all the valleys down to the glaciated limit in Ohio, Indiana, and Illinois have been obliterated, and the whole region has been reduced to a comparative level by the action of the ice; so that the glacial boundary is found to be practically the limit of the prairie region in these States, though as the Alleghanies are approached from the west the comparatively higher elevation of the country, and the consequent increasing depths of the river channels, makes the till in increasing degree insufficient to fill them.

The maximum for the average depth of the glacial deposit over the area in Ohio north of this boundary line is estimated by Mr. E. W. Claypole[1] to be 56 feet. No one at all familiar with the region will be disposed to think this estimate exaggerated.

Recent activity in Ohio and Indiana in boring for gas and oil has given us more definite knowledge of the depth of the glacial deposits over that region than was before possible. The result is to prove that Prof. Claypole's estimate of an average depth of 50 feet is altogether too moderate.[2] Prof. E. Orton furnishes me in advance the figures which he is to publish in his forthcoming report upon the subject. These figures represent the depth of the glacial deposit in fifty-three of the counties of Ohio as determined by the borings in one hundred and twenty-two wells. The average depth of the glacial deposit is found to be upwards of 90 feet (93 feet+). In some of the wells the depth of the glacial deposit was truly phenomenal, as in St. Paris, Champaign County, where in one well rock was not reached until a depth of 370 feet, while in another 530 feet was penetrated by boring, and the well was aban-

[1] See Proc. Am. Assoc. Adv. Sci., 30th (Cincinnati) meeting, 1881, p. 151.

[2] As to the possibilities of error in such calculation, see the driftless area by Chamberlin and Salisbury, Sixth Annual Report U. S. Geol. Survey, p. 207 et seq.

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doned before rock was reached. In Dayton, Montgomery County, the glacial deposit was found to be 247 feet deep; in Cridersville, Auglaize County, 300 feet; in Newark, Licking County, 235 feet; in Lebanon, Warren County, 256 feet; in Osborn, Greene County, 207 feet; in Hamilton, Butler County, 214 feet. The average in various counties is also significant. In Auglaize County six borings give an average depth of 141 feet; in Butler County, four borings average 116 feet.

With reference to the correctness of this representation, it should be remarked that borings prosecuted in this manner are more likely to give an underestimate than an overestimate of the real facts; for, as is well known, it is much easier and less expensive to drill through the sedimentary rocks than through deep deposits of till and looser drift, so that the aim of the prospectors is to begin their wells at points where the rock will be reached at as small a depth as possible. But so completely have the preglacial lines of erosion been obliterated in Ohio that it is impossible to make certain calculations as to the proximity of the rock to the surface. In the deepest drift (530 feet in Champaign County) special effort was made to locate the boring where the superficial deposits were shallow; but, as the result proved, the surface indications were deceptive and a serious mistake was made, involving the contractor in financial disaster. It should, however, be observed that the deep well of St. Paris lies in the line of the terminal moraine of the second glacial epoch, as indicated in the report of President Chamberlin, where the depth of glacial deposits is supposed by him to be exceptionally great.

## CHARACTER OF THE MATERIAL COMPOSING THE TILL.

A uniform characteristic of the surface deposits covering the glaciated region is the intermingling of a great variety of material from widely separated regions to the north.

The significance of the facts observed can best be perceived by comparing observations from extreme portions of Ohio. We will therefore put side by side the deposits in Oberlin, Lorain County, Ohio, and those near Oxford, Butler County.

Oberlin lies 12 miles south of the lake and 252 feet above it, being about 30 miles north of the water-shed. The general surface of the country is remarkably level, though rising gradually to the south; the divide between Black River and the Killbuck, in Harrisville, Medina County, being but 84 feet higher than the general level in Oberlin, while the divide between the Maumee and the Wabash, near Fort Wayne, Indiana, is seven feet lower than Oberlin, and the summit between the Sandusky and Scioto Rivers, in Wyandot County, and between the Mahoning and Grand Rivers, in Trumbull County, do not vary ten feet either way from that already mentioned in Medina County. The drainage sum-

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mits between the Cuyahoga and the Tuscarawas, and between St. Mary's and Laramie Creek, are from forty to sixty feet higher still.

FIG. 2.—Map showing glacial boundary in Ohio.

The following table[1] will be convenient for reference:

Lowest summit between the waters of Lake Erie and the Ohio River:

| | Feet above tide. |
|---|---|
| Mahoning and Grand Rivers, Champion, Trumbull County | 918 |
| Cuyahoga and Tuscarawas Rivers, Summit Lake, near Akron, lowered four feet by the canal | 975 |
| Black River and Killbuck, Harrisville, Medina County | 911 |
| Sandusky and Scioto, Tyamochtee, Summit, Wyandot County | 908 |
| St. Mary's and Laramie Creek, Shelby County | 952 |
| Maumee River and Wabash, near Fort Wayne, Indiana | 825 |

The following data are of value in connection with the above table:

| | Feet. |
|---|---|
| Elevation of Lake Erie above tide | 575 |
| Elevation of Oberlin above tide | 827 |

[1] Prepared by Col. Charles Whittlesey for annual report of the Secretary of State to the Governor of the State of Ohio (Ohio statistics) for 1879, p. 574.

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It thus appears that there could have been no confined body of water over the northern part of the State of sufficient depth to float icebergs of any great size. So that, from the nature of the case, we could not expect to find in this region any extensive deposits from that source; and, least of all, any great amount of striation which could be attributed to floating ice, and with this conclusion the character of the drift in this region corresponds.

The rock nearest the surface in Oberlin is the Waverly sandstone, which in places is but slightly covered by drift, but in other places has suffered extensive erosion, and wells penetrating the drift thirty or forty feet fail to reach the rock. The strata are here dipping toward the southeast at a rate of nine feet per mile.[1] Eight miles to the northwest occurs the line of the outcrop of these sandstones, where are the celebrated Amherst quarries, at an elevation of about one hundred and seventy-five feet above the lake. The lower shelf between these quarries and the lake is occupied by Erie shale, concealed only by a thin covering of drift.

The 175-foot level is marked by a ridge of sand and local gravel, with occasional collections of well-rounded pebbles from three to four inches in diameter. Pieces of fresh wood (supposed to be sycamore), much water-worn, are frequently found from fifteen to twenty feet below the surface of this ridge, and are specially abundant in the level country immediately south of it. Towards the lake there are other series of ridges at lower levels, and in various places where I have observed it, there is in such situations a marked increase of granitic bowlders upon the general surface between the ridges, as if the washing of the waves had carried away the fine material leaving upon the present surface only the bowlders that were originally scattered through a deeper deposit of till, such as characterizes the whole country to the south of the ridges. The geological formations of this vicinity are shown by the following record of a recent boring:

*Record of an artesian well at Oberlin.*

| | Feet. |
|---|---|
| Yellow clay | 11 |
| Blue clay | 10 |
| Red clay | 10 |
| Sandstone | 10 |
| Red shale | 74 |
| Blue shale | 24 |
| Black and blue shale | 737 |
| Limestone | 15 |
| Total | 891 |

From this statement of the situation, the significance of the following facts concerning the composition of the drift at Oberlin will be apparent. From a number of wells dug during the spring of 1886, and

[1] Whittlesey, Ibid., p. 575.

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penetrating the superficial deposit from fifteen to twenty feet, it is evident that it can not have been a deposition in water. Granitic bowlders brought from northern Canada, two feet and more in diameter, are frequently found at all depths in the deposit. Fragments of Corniferous limestone (finely polished and scratched), whose horizon is several hundred feet lower than the situation in which they are found, occur in the drift at all depths. The mass of the deposit is, however, a very tenacious clay, formed by the mechanical comminution of the extensive deposits of shale whose outcrop is to the north and at a lower level. A specimen of this clay, freshly taken from 15 feet below the surface, consisted of about 55 per cent of material so finely comminuted that it was readily held in suspension in water. The remaining 45 per cent consisted of fragments more or less angular, and from one-quarter of an inch in diameter down to the finest sand. Both of these portions effervesce readily in acids, showing that lime is present in the form of carbonate, and that therefore the clay is the result of mechanical comminution and not of chemical disintegration[1]. We give in a note the result of both a mechanical and a microscopical analysis.[2] Among the materials composing this deposit there are granitic and quartzite fragments from northern Canada, Corniferous limestone from below the level of Lake Erie[3], fragments of Erie shale, sometimes two or three inches in diameter, and pieces of Amherst sandstone. All these ingredients are intimately mixed together without any signs of stratification. There are, however, at irregular intervals, belts of stratification in the till wherever I have observed it. For example, in one of the wells mentioned in Oberlin a vein of quicksand a foot or more in thickness was encountered at a depth of 12 feet, but with compact blue till both above and below it.

It is evident that there is no way in which the material composing the till just described could have come into the position it now occupies except by a true glacial movement. The lower level occupied by the strata of the shale (which appears in the till at Oberlin in fragments as well as in finely comminuted particles) demonstrates that the transportation could not have been by floating ice, since with a water level low enough for the shale to have been frozen into the cakes of ice there could not have been depth enough to float it over the higher lands to

[1] See Pres. T. C. Chamberlin, in Am. Jour. Sci., 3d series, vol. 27, 1884, pp. 378–390.

[2] In thirty-eight grains of the material are twenty-one grains of suspended matter and seventeen grains of matter too coarse to be suspended in water. Under the microscope the suspended matter betrays its mechanical origin.

[3] These limestones, however, crop out to the northwest at Sandusky, and to the north on the other side of the lake. But taken in connection with the other facts apparent, we are warranted in drawing the inference that these limestone fragments are from the direction of the ice-flow as indicated in the abundant striæ of the vicinity; and there is no reason why they should not have come from the level of other fragments with which they are associated.

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SECTION OF TILL AT LANE'S MILL, NEAR DARRTOWN, BUTLER COUNTY, OHIO.

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the south, where it is now found. This inference is confirmed also by a comparative study of drift deposits in the southern portion of the State.

The accompanying illustration (plate I) shows perpendicular exposures of till on the banks of Four-mile Creek, at Lane's Mill, west of Darrtown, in the northwest part of Butler County, Ohio. The height of the bank is 65 feet. About half way up from the bottom there is a stratum about two feet thick, which is partially stratified; but both above and below this stratum the deposit is true till, being very compact and containing a great variety of rocky fragments, showing distinct marks of glaciation. The larger portion of the rocky fragments consists of local limestones, and these are abundantly striated. In size these fragments range from two feet in diameter down to minute particles, which are readily held in solution in water. The finer portions effervesce readily in acids. This locality is also that in which fragments and logs of cedar wood are found mingled with the till. Near the left-hand corner a large red-cedar log was found a few years ago in so fresh a condition that it was manufactured into utensils of various sorts, and it still retained its peculiar odor. Fragments of wood are seen projecting from the till both above and below the stratified layer.

I could not detect any essential difference between the till at this locality and that described at Oberlin, except what would be accounted for by the difference of composition arising from the difference in the local material which has been ground up to constitute the matrix. In both cases the material is largely the product of mechanical rather than chemical disintegration. Also, whatever we may say about the stratified stratum in the middle of the bank (shown in plate I), the great masses above and below are clearly the direct deposits of a glacier and not deposits from floating ice. A second view (plate II) from a locality east of Darrtown, is of a similar perpendicular exposure. The unstratified character of the deposit is apparent. The clay and semi-angular fragments are indiscriminately mixed. There is also a well-marked tendency in the flat limestone fragments in the lower portion of the deposit to arrange themselves horizontally. This arrangement, it is true, would, according to mechanical principles, be that which would obtain in case the flat fragments were of uniform thickness and fell through any considerable depth of water. But the chances of their being of uniform thickness and the improbability of their having fallen through great depths of water are such that we may take the horizontal arrangement as proofs of direct glacial deposit rather than of deposit from floating ice.

These instances are but illustrations of what occurs at numerous points not far from the border of the glaciated region as marked in my map. Essentially the same characteristics are found at Avondale station,



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within the limits of Cincinnati itself, and at North Bend, on the north bank of the Ohio River, 20 miles west of Cincinnati, in a deposit 150 feet deep.

## SOURCE OF BOWLDERS IN THE TILL.

The northern origin of much of the material composing the deposits near the margin of the glaciated area is unmistakable, and some of it is surprising both for the distance it has been transported and for the size of the masses transported.

As yet there has been no systematic and complete comparison of the bowlders found near the glaciated margin and the rocky masses to the north, for the purpose of definitely locating the origin of the transported material, and there is such a degree of superficial resemblance between the granitic formations in different localities that no comparison will be satisfactory until the specimens have been both chemically analyzed and examined under the microscope. Still, a superficial examination reveals much of consequence.

In general it is manifest even to the casual observer that everywhere east of the Mississippi River the material composing the till is of northern origin. In Essex County Massachusetts, the bowlders are readily traced to localities in New Hampshire, some of them but a few miles away, and others from the White Mountain region, one hundred miles and more distant. My attention was early attracted throughout that region to bowlders of porphyritic gneiss containing very large and characteristic crystals of feldspar. The nearest ledges containing this class of rock are in the vicinity of Lake Winnipiseogee, in New Hampshire, seventy and more miles away, where the rock is a marked feature. So the whole mass of drift covering Plymouth County, Massachusetts, and that forming the hills of Cape Cod and of the islands to the south, is evidently of northern origin, and much of it from no great distance. Plymouth Rock is a bowlder from the direction of Boston. Prof. N. S. Shaler is able to trace the bowlders removed from a small mountain in the north of Rhode Island, and to estimate their amount with such accuracy as approximately to determine the extent of erosion taking place under a movement extending from that point to the terminal moraine. The material occurs in a triangular-shaped area to the south with its apex at the mountain. (See his forthcoming report.) The bowlders scattered over the surface of the moraine in Long Island consist largely of granite, gneiss, hornblende rock, mica slate, and red sandstone, which are easily recognized as from well-known localities in Rhode Island, Connecticut, and Massachusetts.[1]

Prof. Dana has also described many bowlders in the vicinity of New Haven which have been transported from well known trap-dikes, sixteen miles or more distant, and in a northeasterly direction. One

[1]Natural History of New York, part 4, Geology, part 1, p. 165 et seq.

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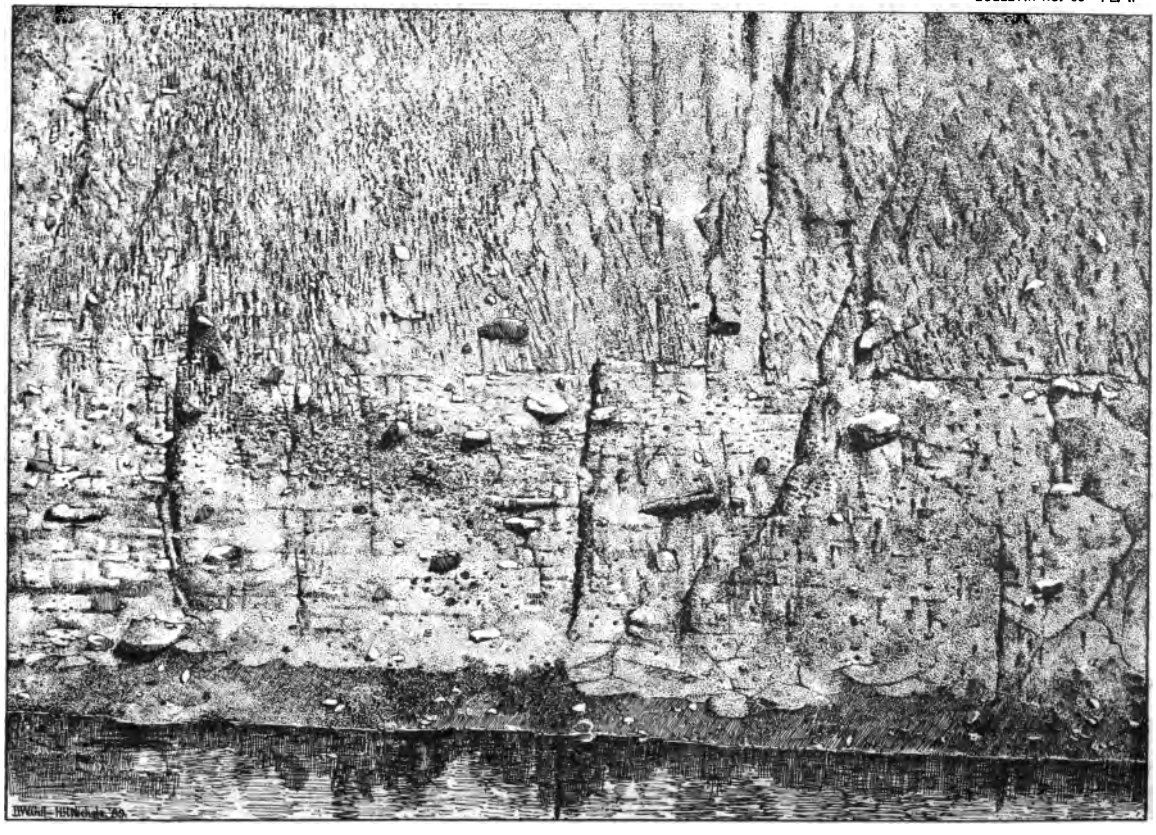

EXPOSURE OF TILL SOME MILES EAST OF LANE'S MILL SECTION.

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of these, called Judges' Cave,[1] on West Rock, 365 feet above the sea, must weigh a thousand tons.

A remarkable train of bowlders in Richmond, Massachusetts, near the summit of the Berkshire Hills and extending several miles was long ago described by President Hitchcock and Sir Charles Lyell, and more recently and accurately by Mr. E. R. Benton.[2]

In New Jersey, according to Prof. Cook, the bowlders are readily traced all along the morainic margin, as belonging to well known outcrops, of trap, blue limestone, and crystalline rocks to the northwest. Near Drakestown, in Morris County, there is a mass of blue limestone which had been worked for years as a quarry without suspecting that it was but a bowlder. "As exposed it measures thirty-six feet by thirty feet, and the quarrying has gone twenty feet in depth. Its vertical diameter is unknown. Around it there are many gneissic bowlders and other drift materials."[3] This mass is about one thousand feet above the sea level, and its native place must have been some miles to the north.

In Pennsylvania the distance from which the glacial material near the border of the glaciated region has been transported becomes at once more evident, because of its unlikeness to the local rocks. West of the Blue or Kittatinny Mountains there are no crystalline rocks in the State. Nor are there any such rocks to the north nearer than the Adirondacks in New York, or the highlands in northern Canada. Yet, granitic, gneissoid, and hornblendic bowlders abound all along the glaciated border, and are an important means of determining the glacial limit. In the valley between Blue Mountain and Pocono Mountain, Monroe County, and on the summit of the Pocono plateau, 2,000 feet above the sea, granitic bowlders from one to three feet in diameter are abundant, though mingled with great piles of local fragments. The granite must have been transported a distance of 250 miles at least, and carried over the summit of the Alleghanies lying to the northwest, and across the valley of the Mohawk in New York. The northern tributaries of the West Branch of the Susquehanna, likewise, bring down into that stream numerous granitic pebbles, showing that the glacial deposits in Lycoming County contain material from the far north which has been carried bodily over the summit of the Alleghanies. On proceeding west, the granitic mountains from which that material could come gradually recede to the north, thus increasing the distance between such bowlders and their possible original home. From Salamanca, New York, southwestward to Cincinnati, the whole country is literally covered, down to the glacial limit, with granitic, gneissoid, and hornblendic bowlders. Near Salamanca such bowlders abound at ele-

[1] See Am. Jour. Sci., 3d series, vol. 26, 1883, p. 347.

[2] Lyell's Antiquity of Man, pp. 355–362; Bull. Mus. Comp. Zool., Harvard Coll., vol. 5, no. 3, 42 pp. with map.

[3] Geol. Survey New Jersey, annual report State geologist for 1880, p. 30.

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vations not far from 1,900 feet above tide and 700 feet above the Alleghany River. In Beaver County they are numerous on the hills to within 6 or 7 miles of the Ohio River, and several hundred feet above it. In Columbiana County, Ohio, a granite bowlder was found measuring 13 by 11 feet and 8 feet out of ground. Others were noted measuring 8 and 5 feet in diameter. In the same vicinity the till contains finely striated fragments of local sandstone, showing direct glacial action on the rocks of the vicinity. In Holmes County, mingled with fragments of granite in the till, were finely polished and striated pebbles of Corniferous limestone, which must have been brought from the other side of the water-shed, in the vicinity of Lake Erie, which is 100 miles distant. Near Lancaster, in Fairfield County, there is a granitic bowlder measuring 18 by 11 by 6 feet out of ground. In Ross County, near Adelphi, Chillicothe, and Bainbridge, granitic bowlders are found on the hills from four to six hundred feet above the valleys, that is, up to one thousand to twelve hundred feet above tide. A hornblendic bowlder 5 by 3 by 2 was noted 550 feet above Bainbridge. In Brown and Clermont and Hamilton Counties granitic bowlders abound on the hills down to the very edge of the trough of the Ohio. Here, also, are numerous bowlders of jasper conglomerate from the region north of Lake Huron or near the lower end of Lake Superior. The variegated pebbles of red jasper and of darker quartzites form a striking feature in the rocks of that northern region. The bowlders of this material found in the vicinity must have been transported nearly six hundred miles. Several bowlders of this description, from two to three feet in diameter, were found in Boone County, Kentucky, a number of miles south of the Ohio River, and between five and six hundred feet above it. Bowlders of this jasper conglomerate are very abundant in Michigan, are not infrequent in northern Ohio, and occur in various localities in southern Indiana—one being observed near Nashville, Brown County, Indiana, near the highest land in the State (about eleven hundred feet). Granitic and hornblendic bowlders are very abundant in Illinois as far south as Carbondale, Jackson County, near latitude 37° 35′ north. The bed rock is also here distinctly striated, showing the transportation of bowlders must have been independent of any stream of water. The distance from this point to the parent ledges can not be less than 600 miles to the north.

## REGULARITY OF DISTRIBUTION OF TILL NEAR THE MARGIN.

### (1) DISTRIBUTION OF THE TILL EAST OF THE ALLEGHANIES.

#### NEW ENGLAND.

Over New England the natural inequalities of the country are partly responsible for the irregular distribution of the till.[1]

In New Hampshire the phenomenon of a sloping mass of till south of a ledge of rock is frequently to be noted. But, as if to check too hasty a generalization respecting the manner of their formation, it has

[1] Chapter by Warren Upham, Geology of New Hampshire, vol. 3, 1878, pp. 285–333.

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also to be noted that in about one-third of the instances in which deposits of till slope up against a rocky eminence the till is on the northern slope in the direction from which the ice came. Moreover, these accumulations sometimes slope both ways, and what is more remarkable still, often surmount in symmetrical form low rocky elevations whose surface is finely polished and striated by glacial action. So often do these lenticular-shaped[1] masses of till surmount low rocky eminences that Prof. Shaler at one time endeavored to explain their origin on the theory that they were but the remnants of a deep ground moraine which had originally covered the whole surface, but, during a supposed depression of the country to the sea-level, had been eroded by the waves wherever they were not protected by the rocky elevations at their base.[2] But these lenticular hills, or drumlins, abound in certain portions of southeastern New England[3] and in central New York south of Lake Ontario.

In southeastern New England these lenticular accumulations "vary in size from a few hundred feet to a third or a half mile in length, with usually about half or two-thirds as great width. Their height, corresponding to their area, varies from 40 or 50 feet to 150 or 200 feet. But whatever may be the size of these hills, they are singularly alike in outline and form, usually having steep sides, with gently sloping, rounded tops, and presenting a very smooth and regular contour."[4]

The prevailing direction of the longer axis of these hills is the same as that of the glacial striæ in their vicinity. In composition drumlins do not differ materially from the ordinary deposits of till in the same region. The material is for the most part unstratified, the clay is very compact; striated stones are commingled with the clay in every portion. There are, however, in these hills, as in the till as ordinarily arranged, occasional layers of stratified material, so that water for domestic purposes is usually found by sinking wells of no great depth. The bowlders upon the surface of the lenticular hills are also both larger in size and more angular in shape than those in the lower part of the deposit. I have not observed anywhere in Ohio, Indiana or Illinois, any marked tendency of the till to assume this lenticular shape. Nor have I been able to detect any generic difference between the composition of these hills and the general deposit of till over the portion of these interior States which I have surveyed. At the same time, it is perhaps worthy of note that the total deposit in the interior States averages a much greater depth than in New England. In Ohio, as already remarked, a reasonable calculation makes the average depth

[1] Hence called by Prof. C. H. Hitchcock "lenticular hills," but Prof. Shaler thinks it best to retain the name "drumlins," given to similar accumulations in Ireland.

[2] See Proc. Boston Soc. Nat. Hist., vol. 13, pp. 196–203.

[3] See Upham, Geol. New Hampshire, vol. 3, pp. 285–309; glacial drift in Boston and vicinity, Proc. Bost. Soc. Nat. Hist., vol. 20, pp. 220–234.

[4] Upham, Geol. New Hampshire, vol. 3, p. 288.

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of the till upwards of 56 feet, while in New Hampshire Mr. Upham estimates that the whole deposit if evenly spread out would not exceed an average of 10 feet. But Mr. Upham now informs me that he thinks his early estimate much too small. This difference may be accounted for in two ways: first, the rocks from which the till of New England is derived are mainly crystalline, and hence of firmer texture than those from which the material of the till near the margin of the glacial limit in the interior is derived. The sandstones, shales, and limestones of the interior would much more readily yield to the disintegrating influences of glacial action than the granite and gneiss of the east would do. In the second place, the depth of the deposit is ordinarily greater over the southern portion of the glaciated region than over the northern, so that the deposits in Massachusetts are noticeably greater than those in New Hampshire for which Mr. Upham made his calculations.

The region under my immediate investigation in the interior States perhaps corresponds, in its proximity to the glacial margin, more nearly with the southern portion of New England.

The extreme southern portion of New England and Long Island are characterized by massive and irregular deposits of glaciated material. The backbone of Cape Cod consists of a line of hills from one to three hundred feet in height and from one to three miles in breadth, flanked on the southern side by extensive deposits of water-worn material. In contour and composition these hills very much resemble the kettle moraine of Wisconsin as described by President Chamberlin. According to my own observation, however, the terminal deposits in southern New England are composed of less water-worn material and contain more striated stones than the corresponding formation in Wisconsin. But like the kettle moraine, this line of deposits on the southern border of New England, abounds in kettle-holes of all sizes and is composed of transported material loosely thrown together. That the deposit on Cape Cod is not truly terminal, however, appears from the fact that the islands to the south are composed of similar deposits. Nantucket, Martha's Vineyard, the Elizabeth Islands, and many smaller islands between, are but the summits of submerged morainic deposits of unknown depth.[1] Farther west this same line of morainic hills continues, appearing near Point Judith in Rhode Island, and running to Watch Hill, and thence through Plum Island and Fisher's Island to the north shore of Long Island as far west as Port Jefferson, where it disappears. The parallel lines of hills, after forming the irregular outline of No Man's Land, Block Island, and the eastern part of Long Island from Montauk Point westward to Sag Harbor and Roslyn, continues to be the chief feature of the country as far as Fort Hamilton and Staten Island, south of New York City.[2]

[1] For description see Upham, Geol. New Hampshire, vol. 3, pp. 301–305, and B. F. Koons, Am. Jour. Sci., 1884, 3d series, vol. 27, pp. 260–264; 3d series, vol. 29, 1885, pp. 480–486.

[2] See Upham, Am. Jour. Sci., 3d series, vol. 18, pp. 86, 198.

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NEW JERSEY.

Across New Jersey the accumulation of loose and glaciated material brought from the north is well marked down to the very margin of any signs of glaciation whatever. But the terminal deposit is not relatively so excessive as along the region eastward through Long Island and Cape Cod. On crossing the Delaware River at Belvidere, and throughout the whole region westward, the relative inferiority of the extreme marginal deposit is still more marked, except in a few localities, which may best be mentioned in this connection.

PENNSYLVANIA.

*In Northampton County, Pennsylvania*, just west of the Delaware River, the character and extent of the glacial deposit continues very much as in New Jersey. Near Middagh's, the most southern point of glacial signs in the county, the deposit is certainly as much as fifty feet in depth, and is, without question, till. This is about six miles west of the river, and is 625 feet above it. Nearer the mountain, not far from Bangor, the marginal deposit is, even at a still greater elevation, from one to two hundred feet in thickness, and for a mile or more is dotted with kettle-holes.

*Monroe County* spans a section east and west from the summit of the Blue Mountains to the summit of Pocono Mountain and the western border of the Pocono plateau looking towards the Lehigh River, a distance of 30 miles. The elevation of the Blue Mountains is in round numbers 1,400 feet above tide; that of the Pocono plateau, 2,000 feet. The valley between them is about eight miles wide, and is but 620 feet above tide. At Saylorsburgh, in the middle of this valley, there are extensive kettle-holes, and the deposit of till is very deep (Prof. Lewis estimates it as "several hundred feet") and covered with large bowlders, some of which are from the Adirondacks, 250 miles away. Five or six miles away, on the summit of the Pocono plateau, 1,400 feet higher, the marginal deposit is equally remarkable. For many miles in width a level, sandy plain extends in all directions. The soil over that portion of it situated south of the glaciated region is thin, being composed simply of the superficial disintegration of the compact Pocono sandstone. Upon going north in Tunkhannock township, one suddenly strikes into a glacial accumulation (near the boundary of Tobyhanna township), which is remarkable at once for its length, its height, its composition, and the abruptness of its southern margin. For a distance of about twelve miles the accumulation forms a marked feature of the landscape, and is known in the locality as "Long Ridge." This is truly morainic in character, is one hundred feet or more high, consists of a confused collection of bowlders (some of granitic character from the far north), and incloses near its margin numerous small lakes which have no outlet. These are neither more nor less than kettle-holes, and they are specially remarkable from the fact that some of

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them are near the eastern margin of the plateau, which here forms an escarpment of several hundred feet. A little farther west this moraine so obstructs the outlets of several small streams flowing northward as to form small lakes to the south of it.[1]

*Luzerne County.*—It is unnecessary to do more than merely mention a few other places in Pennsylvania where the abruptness and amount of the terminal accumulations are noteworthy. But it may be well to note that upon the western flanks of the mountain in Luzerne County, between the Lehigh and the Susquehanna Rivers, the southern-margin of glacial action is very sharply defined, so that, according to Prof. Lewis,[2] the southern limit of the glacier can be determined to within a few yards. The accumulations in the valley of the North Branch of the Susquehanna, above Beach Haven, are also very large, and are unquestionably a direct glacial deposit, as can be seen to good effect by comparing them with the material near the river, at and below the intersection of the glacial border, where extensive terraces, 75 feet high, line the stream for one-fourth a mile on either side. Beach Haven is but 530 feet above tide.

*Columbia County.*—Another striking mass of glaciated material in the same vicinity occurs in Sugarloaf township, Columbia County. This is in the valley of Fishing Creek, west of Shackshinny Mountain. The valley is filled from side to side with a heterogeneous collection of large sandstone and conglomerate bowlders (some of them six feet in diameter), mingled with unstratified finer material, and to a depth of seventy-five feet or more. This deposit extends several miles south on the east side of the valley, but is entirely absent south of this point on the western side. The elevation of the valley is about one thousand feet above tide. The Alleghany Mountain rises 1,100 feet higher four miles to the north. This is but four or five miles south of the striæ on the summit of the mountain, mentioned on p. 40. A few miles west of this point the signs of glaciation cease.

*Lycoming County.*—On the summit of the Alleghany Range, near Ralston, in Lycoming County, the deposits are thick on the highlands east of Lycoming Creek, and about eight hundred or one thousand feet above it. But the narrow valley itself contains nothing but water-worn material, both to the south and for several miles to the north of Ralston.

NEW YORK.

*In Cattaraugus County, New York,* the terminal deposits are specially abundant in the township of Great Valley south of Ellicottsville and upon the hills south of Randolph. Great Valley, just south of the village of Peth, is filled with till from side to side (about one-eighth of a mile) to a depth of at least 60 feet and for a long distance. Scratched fragments and pebbles of granite and gneiss are abundant in the de-

[1] Second Geol. Survey Pennsylvania, Z, pp. 74–78. [2] Ibid, p. 103.

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posit at this point and to the north, but to the south there is nothing in the valley except water-worn material arranged in regular terraces. At Steamburgh, about 20 miles further west, in the old valley east of Randolph, wells penetrate the stratified gravel 70 feet without reaching rock, and probably would have to go much deeper to reach it. This was probably, according to Prof. Carll,[1] the preglacial outlet of the Upper Alleghany River, which is known not to have flowed at that time south of Warren, Pennsylvania, since its upper and buried channel is much deeper than that below Warren.

## (2) DISTRIBUTION OF THE TILL WEST OF THE ALLEGHANIES.

### GENERAL REMARKS.

In considering the glacial deposits of western Pennsylvania and of eastern and southern Ohio it is important to bear in mind the ordinary elevation of the country above tide and its preglacial condition. From Salamanca, New York, to Cincinnati, Ohio (a distance in a straight line of about 380 miles), the general course of the glacial boundary is southwest, and is approximately parallel with the axis of the Appalachian Mountains, and continues throughout not far from the northwest outcrop of the Appalachian coal-fields, being inside the line of outcrop as far as Knox County, Ohio, and from thence to the Ohio River in Brown County, passing over a country characterized by extensive outcrops of Waverly sandstone. Over all this region preglacial erosion had been most extensive, as is evident to a superficial observer, from the long, deep channels cut by all the streams through the coal measures outside the glacial limit, and where there has been little to disguise the effect of this long-continued erosion. The Ohio River, from Louisville, Kentucky, up to Pittsburgh, Pennsylvania, occupies a valley of erosion averaging about a mile in width, and bordered on each side by parallel horizontal strata of rock rising in nearly perpendicular bluffs from three to five hundred feet in height. The same trough continues in similar proportions up the Alleghany River to near its source, except that it is narrower and in its upper portions deeper. Furthermore, deep as is this valley, there is abundant evidence that before the glacial period it was still deeper, it having been filled up, as estimated by Newberry,[2] more than one hundred and fifty feet by a postglacial river deposit. For example, at Cincinnati the gravel and sand have been repeatedly penetrated to a depth of more than one hundred feet below the bottom of the river without reaching the rock. At New Philadelphia, Tuscarawas County, Ohio, borings show that the old bottom of the Tuscarawas River was 175 feet below its present depth. Near New Castle, Pennsylvania, the bottom of the old trough of Beaver Creek is shown to be 150 feet below the present bottom.

[1] Second Géol. Survey Pennsylvania, III, pp. 330–439.
[2] Geol. Survey, Ohio, vol. 2, pp. 1–80.

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In the same manner all the streams tributary to the Ohio occupy narrow, deep valleys of erosion, entirely devoid of waterfalls, showing that in all cases they have been at work in their present valleys from the very earliest times. The difference between the elevation of the country about Salamanca and that at Cincinnati corresponds very nearly with the fall of the Alleghany and the Ohio Rivers between those points. The Alleghany River at Salamanca is 1,360 feet above tide. The country to the north and west is about 1,900 feet above tide. The Ohio River at Cincinnati is 447 feet above tide. The elevation of the surrounding country is between nine hundred and one thousand feet above tide. North of the glacial limit there is every reason to suppose that preglacial erosion had produced effects corresponding to what is now visible throughout southeastern Ohio, southwestern Pennsylvania, and West Virginia. But to a great extent these preglacial channels have been completely filled up with till, so as to make important changes in the line of drainage and to give an entirely different aspect to the whole glaciated region from that borne by the country outside of the limit. Indeed, as remarked above, the glacial boundary throughout southwestern Ohio and the whole of Indiana and Illinois corresponds very closely with the boundary of the prairie region in those States, so that the natural scenery, the character of the soil, the water supply, and nearly all the elements determining the vast agricultural interests of those States have been produced by the ice movement during the glacial period. The till which is spread over this area represents what Newberry calls "the grist" of the continental glacier, and altogether constitutes an immense mass, amounting in Ohio alone to a stratum averaging more than sixty feet in depth over about twenty-five thousand square miles. As compared with the deposits in New England, this is so nearly uniform in its deposition that it has been beyond my power, if not my province, to trace any extensive system in the irregularities which appear. The results of the attempt to trace such a system are given by President Chamberlin.[1] I will content myself with briefly indicating the approximate amount of deposition along a belt from ten to twenty miles wide, forming the southern and eastern margin from Salamanca, New York, to the Mississippi River, taking the counties in order.

### PENNSYLVANIA.

*Warren County.*—In the Conewango Valley above Warren, in Warren County, the glacial accumulations are very marked, filling it from side to side, forming a well-defined ridge rising abruptly about seventy feet on its northern side, near Ackley Station. For about two miles the material of this deposit is clearly till, but it gradually changes into water-worn material, which is spread along the margin of the stream as a regular terrace. This morainic deposit rises diagonally upon the flanks of the

[1] Preliminary paper on the terminal moraine of the second glacial epoch, Third Annual Report U. S. Geological Survey, pp. 330–335, 339, 341.

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hill to the east for a long distance and to a heighth of several hundred feet. Upon the west side of the valley the glacial deposits are deep all over the northern tier of townships from Pine Grove westward, and they appear as if pushed up to the watershed between Lake Erie and the Alleghany, which is here 1,900 feet above the sea, more than 1,200 above the lake, and about 700 above the Alleghany.

The till in many places is certainly twenty-five feet in depth, and extends in a continuous sheet northward as far as Jamestown, New York. It is pushed far up upon the northern slope of Pike's Ridge, in Sugar Grove township, Pennsylvania, to a height of about four hundred feet above the country to the north. In the southwest part of the county granitic bowlders and striated stones are numerous upon the high land in the southern part of Deerfield township. This is several miles nearer the Alleghany River than the line as determined by Prof. Lewis and myself in 1881 for the Pennsylvania Survey.

*Venango County* contains a glacial deposit of considerable depth near its western border; but the deep accumulations are for the most part in the valleys now occupied by streams. Here also, as in Warren County, the glacial limit must be put several miles nearer the Alleghany River than as delineated by Prof. Lewis and myself in 1881. Granitic bowlders and striated pebbles abound in Cherry Tree, Oakland, Sugar Creek, and Sandy Creek townships, at an elevation of about six hundred feet above the river and about one thousand seven hundred feet above tide.

*Crawford County* lies wholly within the glacial limit, and with the exception of its southeastern portion is uniformly and deeply covered with till.

*Mercer County* also lies wholly within the glaciated area, and is deeply covered with till, except upon its higher summits, which contain numerous glacial striæ.

*Butler County.*—The glacial limit barely grazes the northwestern portion of Butler County, passing through Mercer, Slippery Rock, and Worth townships. Granitic bowlders are numerous down to very near the margin.

*Lawrence County* is completely enveloped in till, with the exception of the two southeast townships. The depth of the till, even upon the higher lands, as at Mount Jackson, certainly approaches 50 feet.

*Beaver County.*—Till is pretty deep over the extreme northwestern part of Beaver County, in Darlington township. Bowlders and thin deposits of till are found upon the highlands ten miles farther south, to within about ten miles of the Ohio River, but none could be found upon the high land beyond those points. The bowlders found in the terraces at the mouth of Beaver Creek were transported down the stream by water.

OHIO.

*Columbiana County.*—The northern half of Columbiana County is deeply covered with till, while it is entirely absent in the southern half.

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Within two miles of the southern boundary of the deposit, in the most western township, the till is thrown up into hummocks, and incloses kettle-holes of moderate size upon the highest land, constituting at that point the water-shed between the Mahoning and the Tuscarawas rivers. Wells are reported as penetrating the till 50 feet without reaching rock. Throughout the country, especially in the eastern part, granitic bowlders are found upon the high lands along a belt four or five miles south of the deeper deposit.

*Stark County* is deeply enveloped in till all over its northern and western half, while the southeastern part is completely devoid of glacial marks. Two or three miles west of Canton there is a remarkable series of ridges and kettle-holes, ending in Buck Ridge, which rises 85 feet out of an extensive gravel plain, with a base of 570 feet, and ascending from the east side with a slope from 18° to 25°. This kame—for so it properly is—is coarsely stratified, and contains many granitic pebbles and bowlders. One bowlder, about the middle of a cross-section half way up, measured nearly five feet in diameter. To the north the ridge continues to an indefinite distance, inclosing large kettle-holes. One of these was 300 feet long and 40 feet deep, with the bifurcated edges of the ridge as its rim. This seems to be the southern extension of the large kame-like deposits which abound between Akron and Ravenna, upon the water-shed between the Cuyahoga and the Nimishillin, about twenty-five miles to the north. The numerous lakes throughout that region are all "kettle-holes." The extreme southwestern part of Stark County is deeply covered with till, and there is an immense kame-like accumulation near the Tuscarawas River, and rising 154 feet above it, in the southern part of Bethlehem township.

*Holmes County.*—The northern half of Holmes County is deeply covered with till, while it is completely absent in the southern half, and the line is very sharply defined. The Killbuck River divides the county into two equal portions east and west, occupying a valley about a mile in width, and about 500 feet below the general level. The southern half of the county is very much broken, being everywhere cut up into deep gorges by the streams. Throughout the northern half, these gorges have been entirely obliterated by the glacial deposits. Deposits of till from twenty-five to thirty feet in depth appear at numerous places near the highest land in the county. In a broad place where these small streams unite in the valley, five miles north of Millersburgh, is a kame-like accumulation rising 125 feet above the stream, containing scratched stones. Near Millersburgh a cut in the till showed a very fresh appearance 20 feet below the surface, there being no signs of oxidation at that depth. There are extensive terraces on the Killbuck River near Killbuck post-office, rising 120 feet above the river.

*Knox County.*—All but the extreme eastern portion of Knox County is deeply enveloped in till. The glacial boundary is here running a few degrees west of south. At Danville, wells were reported penetrating

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126 feet (probably in a preglacial channel) through yellow clay, blue clay, gravel, quicksand, and cemented gravel without reaching rock. The railroad cut shows glaciated material from twenty-five to forty feet deep for a distance of about 400 yards. This is on the extreme eastern limit of the glaciated area.

*Licking County* is enveloped with till to a depth of fifteen to thirty feet west of the two eastern tiers of townships, and the fringe of scattered glacial deposits outside is narrow.

*Perry County* lies wholly outside of the glaciated region, with the exception of the northwestern township, where, at Thornville, the glacial deposit upon the hills south of the old reservoir is certainly 35 feet in depth. Large bowlders are numerous.

*Fairfield County* is deeply covered with till, with the exception of its three or four southeast townships, which in places very near the margin is certainly 40 feet in depth at an elevation of 450 feet above the canal at Lancaster.

*Ross County.*—The glacial limit passes through Ross County diagonally from northeast to southwest. The accumulations at Adelphi, in the extreme northeast corner of the county, in the valley of Salt Creek, are in general very fresh in appearance and show an exposure of 188 feet. The same formation rises to 200 feet a mile or two west. A few scattered pebbles of granite were found three or four miles outside of this limit upon hills 400 feet above Salt Creek, and glacial accumulations are continuous in the Scioto Valley to Circleville. In Green township, in the eastern part of the Scioto Valley, there are immense kame-like ridges of gravel largely composed of limestone fragments, rising 150 feet (barometer) above the plain. Near Lattas P. O., in Twin township—550 feet (barometer) above the Scioto Valley at Chillicothe—a well upon the farm of J. McConnell penetrated till 31 feet (12 feet yellow clay, 4 feet blue clay, 10 feet yellow clay, 5 feet gravel). Three miles north of this is a broad valley 400 feet lower. Wood was found in this well in the clay 13 feet from the surface. Scattered glacial deposits upon the summit are found three or four miles farther south; but the deposit continues at a great depth to the west as far as Highland County.[1]

*Highland County* is completely enveloped in till, with the exception of its southeast corner. Over the northern and western half the deposit is deep, but rather thin southeast of Hillsborough. A mile or two south of Hillsborough there is an extensive deposit, about 40 feet thick, of cemented gravel containing granitic pebbles, having nearly the elevation of Hillsborough itself, which is 500 feet above Chillicothe, and 700 feet above low water at Cincinnati, 1,135 above tide.

*Brown and Clermont Counties* are deeply covered with till over their northern portion, and glacial deposits are more or less marked down to the Ohio River as far east as Eagle Creek, Brown County. In the south-

[1] For further particulars concerning the deposits in this county along Paint Creek see p. 93.

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ern part of these counties the till is pretty generally of a reddish color, showing thorough oxidation. Lewis and Pleasant townships, in Brown County, on the Ohio River, abound in these deposits of till down to the very margin of the trough of the Ohio, where the general level is from 400 to 450 feet above the river. Numerous deposits within a mile of the escarpment were noted from ten to twenty feet in depth, and contained granite bowlders three or four feet in diameter.

Nearly the entire water-shed, many miles in width, east and south of the East Fork of the Little Miami, and occupying and covering the western part of Highland, the northern part of Brown, and the southern part of Clermont County, and lying from 400 to 500 feet above the Ohio River, is covered by a level and uniform deposit of loamy soil, fine and light colored at the top, with gravel toward the bottom from three to seven feet deep. Granite is a frequent constituent of the gravel, the surface is a dead level, and the land is difficult to drain. The deposit is similar in every essential respect to those afterward to be described in the southeastern counties of Indiana and over a large part of the southern portion of the glaciated region in Illinois. The fine deposit at the surface is in these counties thin, being scarcely ever more than two or three feet in thickness, and resembles in composition the upper part of the loess appearing so extensively in Illinois and farther west.

*Hamilton County.*—Clearly marked glacial deposits are by no means continuous over Hamilton County, but they are scattered over it in a somewhat perplexing manner. In Anderson township, in the southeastern corner of the county, upon the Ohio River, much of the elevated portion of the country (375 feet above the river) is covered with till from 15 to 20 feet in depth, and granitic bowlders are abundant. In the southern sections of Columbia township, cuts in till are frequent from 30 to 40 feet in depth. At Avondale and Walnut Hills, in the upper part of the city of Cincinnati (from 250 to 350 feet above low-water mark), cuts in till from fifteen to twenty feet in depth are exposed. In this there is no appearance of stratification; granitic fragments up to 20 inches in diameter are abundant, and in general are not water-worn; striated fragments of local rock and Corniferous limestone from the northern part of the State are also abundant. Upon the western side of Mill Creek no distinct deposits of till could be found upon the highlands in the townships bordering the Ohio, nor in Green township, still farther to the north. The region, however, is covered pretty generally with a deposit from six to ten feet in depth, consisting of fine clay, of a whitish yellow for the first three or four feet from the surface and a reddish color below, with some gravel near the bottom, and occasionally a striated pebble. The general elevation above the river is not far from 400 feet. At North Bend, in Miami township, a preglacial valley, formerly connecting the Big Miami with the Ohio, is filled with till to a height of 160 feet above the river. Striated pebbles in this are numerous. Colerain and Springfield townships, in the northern part of the county,

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are, over their southern portions, pretty generally covered with from ten to fifteen feet of clay comparatively free from pebbles; but in their northern part, near Pleasant Run, deposits of true till are deep and abundant.

*Butler County*, to the north of Hamilton County, is everywhere deeply enveloped in till, fresh sections of which, near the city of Hamilton, contain undecayed specimens of wood, and show as little signs of oxidation as anything in the northern part of the State.[1]

KENTUCKY.

Campbell, Kenton, and Boone Counties form a sort of promontory looking towards the north, with the Ohio River on the east, north, and west sides. Since the direct glacial deposits come down to the river banks in Clermont and Brown Counties on the east in Ohio, and in Dearborn, Ohio, Jefferson, and Clarke Counties in Indiana, it becomes of special interest to note the facts over the intervening portion of Kentucky with care.

*Campbell County.*—The hills in Carthage precinct facing the river to the east and opposite New Richmond, Ohio, about twenty-five miles above Cincinnati, are enveloped with a deposit of till from ten to fifteen feet in depth in which granitic bowlders are numerous. This extends to an elevation of from 350 to 400 feet above the river opposite New Richmond, but none could be found upon the hills in the southern part of the precinct. Nor could any till or granite pebbles be found upon the summit between the Ohio and Licking Rivers in this county from Alexandria to Dayton (the general level being about 400 feet above the river). The soil, from six to ten feet deep, is clay, being yellow near the surface, but dark gray below. A deposit of sand near Alexandria upon the summit is a decomposed remnant of sandstone.

*Kenton County.*—A détour from Visalia northwest towards Florence (over elevations ranging from three hundred and fifty to five hundred feet above the river) discloses no glacial signs until reaching the Boone County line, three miles southeast of Florence. Here seven miles south of the Ohio, there suddenly appears a stiff clay deposit containing numerous granitic pebbles three or four inches through (see specimens 91 and 92). From this point northward towards Florence granitic bowlders abound. Five were measured which were each upward of two feet in diameter. The covering of the soil was only from two to three feet (the elevation is about five hundred feet above the Ohio).

North of this, a railroad cut at Erlanger (475 feet above low-water mark in the river), shows clay six feet, containing small pebbles of quartzite, limestone and granite.

From Erlanger to Covington a deep deposit (from twenty to twenty-five feet) of loess merging into loam, with some gravel at the bottom, everywhere appears along the road.

[1] See p. 49.

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*Boone County.*—One and a half miles southwest of Florence a bowlder of jasper conglomerate, three and a half feet in diameter was found in the headwaters of a small stream emptying into Gunpowder Creek (elevation about five hundred feet above the river at Cincinnati). Two miles west of Florence there are other bowlders of this jasper congolmerate with thirty or forty granitic bowlders, many of them two or more feet in diameter. These also are in a branch of Gunpowder Creek and 500 feet above Cincinnati. This conglomerate is identical in composition with that found in place on the south shore of Lake Superior and to the north of Lake Huron, the bowlders from which are widely scattered over Michigan, Indiana, and northern Ohio.

One mile east of Hebron there is a deposit of till 12 feet or more in depth, and 450 feet above the river. The whole surface of the country about Hebron is covered with a loamy deposit containing occasional scratched stones and pebbles.

From Petersburg to Big Stone Lick the summits of the bluff, up to about 450 feet, and perhaps higher, are enveloped with a loam containing numerous granitic and other pebbles. There is no appearance of stratification. Near the headwaters of Middle Creek, at an elevation of 300 feet above the river, six miles southeast of Petersburgh and three miles east of Belleview (Grant post-office), the washed pebbles of this gravel are cemented together by an infiltration of lime, forming perpendicular exposures of 50 feet, where cut through by the streams. The pebbles are mostly lime rock of the Cincinnati series, but some, a foot or more in diameter, are granitic.

An extensive deposit of this loam appears on the highlands south of Gunpowder Creek, two miles northeast of Big Bone Lick, by Big Bone Baptist Church, near the junction of Hamilton and Union precincts, 500 feet (barometer) above the river.

A section made still farther south, from Glencoe to Warsaw, in Gallatin County, failed to disclose similar deposits there.

Similar to the conglomerate at the headwaters of Middle Creek is that facing the river at the mouth of Woolper Creek, known as Split Rock (see plates III and IV), which show the cliffs of conglomerate across the creek from Split Rock.

The pebbles in the cemented masses are mostly of limestone, and are very coarse, individual pebbles frequently being from three to four feet in diameter. Granitic pebbles are infrequent. One was found, however, measuring two feet in diameter. The cliffs of this conglomerate, at the mouth of Woolper Creek, rise 185 feet above low water, and the material is cemented together by an infiltration of lime. Kamelike ridges extend for two miles south of Woolper Creek, on the way to Belleview. These are composed of rather fine material, and are 160 feet above the river. The terrace upon this, the Kentucky side of the river, for two miles or more below Woolper Creek, is remarkable for its height, being more than 100 feet above the river, and 56 feet higher than the high-water mark of January, 1883.

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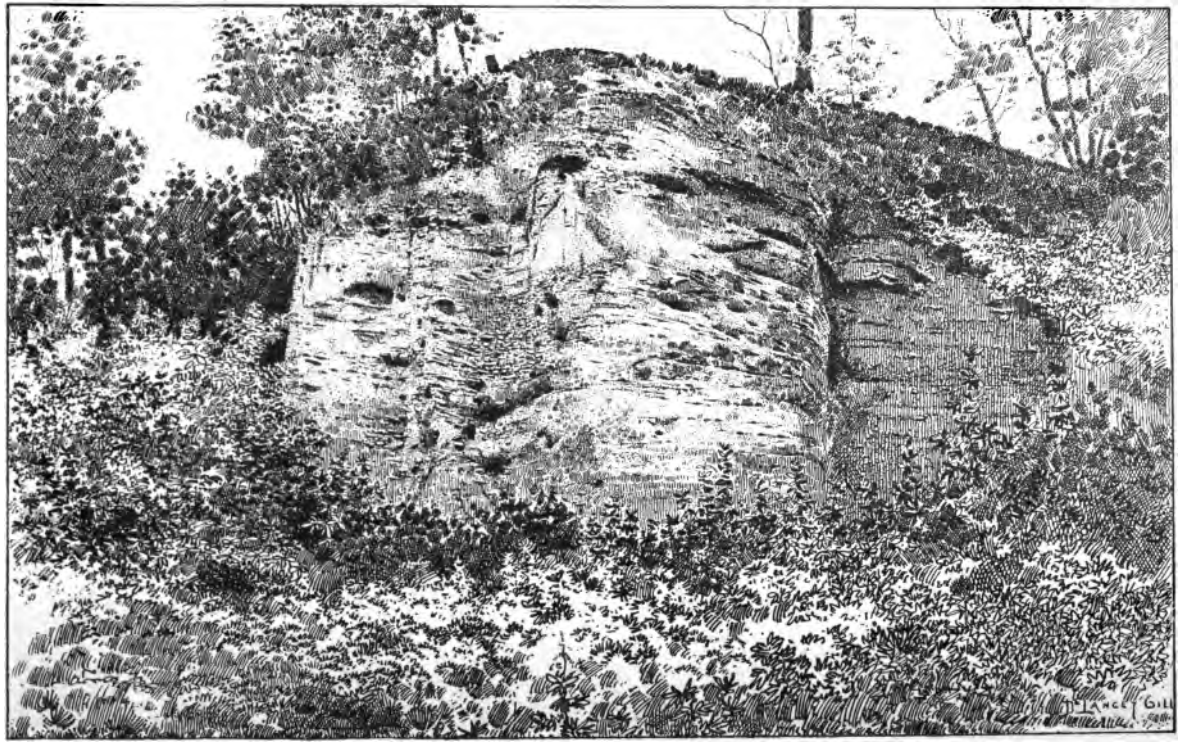

CLIFF OF POST-GLACIAL CONGLOMERATE SOUTH OF WOOLPER CREEK, NEAR SPLIT ROCK, KENTUCKY.

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*Trimble County.*—South of Madison, Indiana, on the opposite side of the river, in Kentucky, the level-topped table-land (450 feet, barometer, above the river) is covered for several miles with a yellowish loam or loess, two to five feet, graduating into a stratum containing a large number of flint chips, but no granitic pebbles. There were, however, some quartzite and compact red sandstone pebbles, giving some signs of glaciation; also near the river a few granitic pebbles were found 440 feet (barometer) above the river.

INDIANA.

In Indiana the glacial boundary line still continues to bear in a southerly direction through Ohio, Switzerland, and Jefferson Counties, grazing the edge of Kentucky again opposite Madison, and reaching its southernmost point near Charlestown, in Clark County.

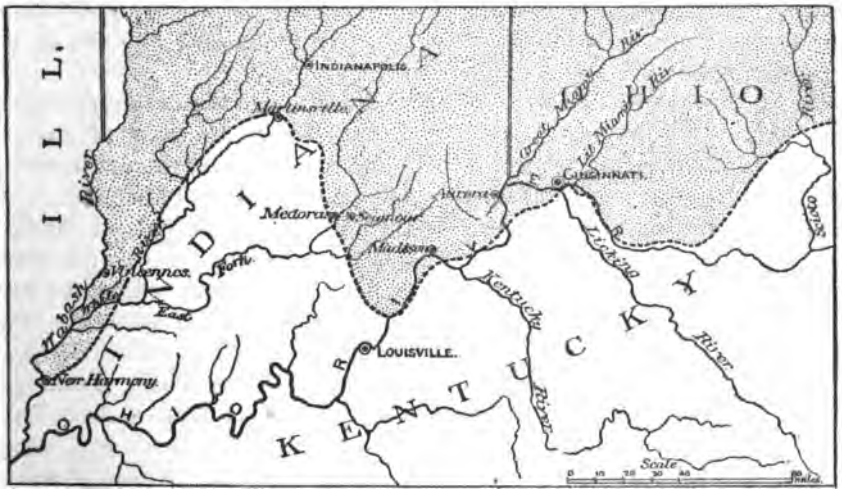


FIG. 3.—Map of southern Indiana, showing glacial boundary.

From here it bears again to the north through Scott and Jackson Counties to the line between Bartholomew and Brown, and follows this to the northeastern corner of Brown. There again it turns to the southwest, touching the northeast corner of Monroe, where it again bears north for 10 miles, to near Martinsville, Morgan County. Here the line turns west and south, passing diagonally through Owen, Greene, Knox, and Gibson Counties, and into Posey County to New Harmony.

*Dearborn County.*—At the Junction of the Miami and the Ohio, just above Lawrenceburgh, the valley is between two and three miles wide, and the level-topped highlands on the west rise to an elevation of 500 feet. Thin deposits of till were found upon these highlands with scattered granitic bowlders over the whole southern part of the county. The intervale upon the Ohio is here bordered on the west by a stratified terrace of water-worn material from one-fourth to one-half mile wide, 80 feet above high-water mark, largely composed of pebbles two or three inches



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in diameter. Opposite Lawrenceburgh remnants of this appear on the Kentucky side, and it continues at a similar height on the east bank for some distance up the Miami, in Ohio.

*Ohio County.*—At Hartford, Ohio County, south of Laughery Creek, a deposit of clay, gravel, and small granitic pebbles (thrown up into small ridges and knolls) rises upon the north slope of the plateau to a height of 250 feet. Gold is found in this deposit. Upon the table-land 450 feet above the river, granitic bowlders, from two to three feet in diameter, occasionally occur.

*Switzerland County.*—Upon the highlands, one-half mile back from the river, at Florence, York township (elevation 350 feet above the river), there is no appearance of glaciation, the clays being all residuary. An extensive terrace on the east side of the river is 100 feet above low-water mark. The highlands in Jefferson and Craig townships, northwest of Vevay (475 feet above low water), are covered with a deposit of reddish clay, from two to three feet thick, abounding in granitic pebbles.

*Jefferson County.*—On the edge of the level-topped highlands, at North Madison, 475 feet above low-water mark, there is a deposit of clay 20 feet deep, light yellow for a few feet below the surface, then reddish in color, with much flint and many small pebbles, some of which are of granite and are striated, especially through the lower half of the deposit. The fine material gradually merges into the coarse, and there is no stratification. The flint comes from the decomposition of limestones in the region further north. Detours made from here (30 miles north to Osgood, Ripley County; 25 miles northwest to Vernon, Jennings County, and 15 miles west-northwest to Paris, Jennings County) show that the whole table-land is covered with a formation similar to that described. This is of varying degrees of thickness, being sometimes 30 feet and more in depth on the highland. Granitic bowlders and striated stone pebbles are abundant, but there are no knobs or ridges of drift.

Hanover and Saluda townships are of the same elevation and present the same features with the region north of Madison. Granitic bowlders are abundant on the surface, sometimes two or three feet in diameter, and the till is occasionally from twenty to thirty feet deep upon the highlands, with granitic bowlders near the bottom.

*Ripley County.*—At Milan (about five hundred and fifty feet above the river at Aurora), a well, according to Prof. Borden[1], gives the following section:

| | Feet. |
|---|---|
| 1. Light-colored clay soil | 10 to 14 |
| 2. Yellow clay, with flint, gravel, and fossil-corals | 12 |
| 3. Blue glacial clay | 12 |
| 4. Coarse, yellow sand, with recent shells and water | 8 |
| 5. Blue clay, muck, containing roots and limbs of trees | 8 |
| Total | 54 |

[1] Seventh Annual Report, Geol. Survey, Indiana, for 1875 (1876), p. 195.

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A NEAR VIEW OF CLIFF OF POST-GLACIAL CONGLOMERATE SHOWN IN PLATE III.

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*Jennings County.*—In Bigger township, in the southeastern corner of Jennings County, wood was reported from two wells in hard blue clay, 12 and 30 feet below the surface.

Prof. Borden reports the following section[1] from a well at Paris Crossing:

| | Feet. |
|---|---|
| 1. Light-colored clay, with deeper shades below | 10 |
| 2. Ocher-colored clay, with flint pebbles, increasing in hardness towards the bottom | 19 |
| 3. Very hard bed clay and gravel | 2 to 3 |
| 4. Blue drift clay, very sandy, with water; also limbs, twigs, and roots of trees, continued to the depth of | 7 to 10 |

*Clark County.*—Through Washington, Bethlehem, and Owens townships, the characteristics described in Jefferson County continue. Large striated granite bowlders, three to four feet through, abound near Bethlehem, about half way up to the summit from the river. Some till appears as far south as Charlestown; but thence to Jeffersonville, and turning northwest across the northeastern corner of Floyd County to Wood Township, Clark County, and thence on northwest through Washington and Lawrence Counties, no till or transported bowlders are to be found. Glacial deposits are found only on returning east to Brownstown, Jackson County. A prominent feature of the country from the eastern part of Floyd County to the northeastern part of Brown County are the knobs of Waverly sandstone, rising several hundred feet above the surface to the east, and dipping gently westward so as to underlie the coal which is in the western part of the State, corresponding to similar formations dipping in the opposite direction in the Scioto Valley of Ohio.

*Scott County* and the southeastern part of Jackson I have not examined, but have assumed that the limit lies east of the knobs just named.

*Jackson County.*—Till with granitic pebbles and striated stones was found two miles southeast of Brownstown, bordering the sandstone knobs. North of Brownstown, six miles across the intervale between the East Fork of White River and White Creek, till rises about fifty feet from the plain against the foot hills. But the highlands in Salt Creek township show no glacial deposits.

*Bartholomew County.*—In the southwestern corner of Bartholomew County till, abounding in granitic pebbles and striated stones, runs up on the highlands to within about two hundred feet of the summit of the sand hills; but it is absent from the southeastern corner of Brown County. Sections in Ohio township show it to be at least forty feet in depth, and it continues, like a flat-topped terrace, eastward toward the East Fork of White River. Harrison and Union townships are covered with till from the east to within about two miles of the Brown County line, where it ceases upon the flanks of the sandy knobs, at a height of about two hundred feet above the valley. Sections show this to be at least fifty feet deep.

[1] Seventh Annual Report, Geol. Survey, Indiana, for 1875 (1876), p. 172.

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*Decatur County*, to the east, is completely enveloped in till, but neither in that county nor in any south of it was my own attention called to anything like moraine hills, such as were described in the Eastern States, though I drove from Clarksburgh, in the northeastern corner of the county, to Greensburgh, and thence south through Osgood, Ripley County, to the Ohio.

*Johnson County.*—The southern part of Johnson County is completely enveloped in till, the deposits being sometimes ninety feet and more in depth.

*Brown County.*—The sandy knobs stretching northward from Floyd County, attain in Brown County, south of Nashville an elevation of 1,147 feet above tide. No glacial deposits were found upon these knobs along the eastern border of the county until reaching the extreme northeastern corner.

Till continues from Johnson County into the northeastern part of Hamblin township, Brown County, and rises to within about three hundred feet of the summit of the knobs. There are no granitic bowlders in the beds of the streams running east from the knobs, but many very large ones are found near the glacial margin, one being five feet in diameter. Gold is also found here, as in Ohio County.

The northwestern part of Hamblin township and the northern part of Jackson township are covered with deep deposits of till, being fifteen or twenty feet deep at Georgetown, and rising to an elevation of 200 feet above Bean Blossom Creek. In the valley of Big Salt Creek, at Nashville, there is no till; but a few granitic pebbles and bowlders are to be found. Northwest from Nashville, near the water-shed between Big Salt and Bean Blossom Creeks, and on the south slope, bowlders of granite and jasper conglomerate, from three to five feet through, were found. Till also was encountered at Needmore, Jackson township.

*Monroe County* is wholly free from any glacial deposit, except in the extreme northeast corner.

*Morgan County.*—Jackson township is completely enveloped in till, often from thirty to forty feet in depth. At Morgantown, wood is reported as found in a well one-fourth mile from the creek, 30 feet below the surface. At Mahalasville, the glacial deposit terminates on the northeastern side of the valley of Big Indian Creek, in kame-like hills 107 feet high. The gravel in this hill is mostly fine, but contains bowlders of decaying granite, two and a half feet, at different elevations. The valley of White River at Martinsville, Washington township, is about one and one-fourth miles wide, consisting mostly of intervale. Till appears on hills east of Martinsville, but there is none southwest.

Jefferson township is covered with deep deposits of till to about one mile south of its center, where it suddenly ceases.

Ray township contains glacial material only in its extreme northern part.

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*Putnam County* is completely enveloped in till.

*Owen County.*—In Owen County the glacial line turns again to the southwest, running through Harrison, Taylor, Montgomery, Morgan, Lafayette, and Jefferson townships.

The southeastern part of Harrison township is unglaciated; but glacial deposits are continuous over the northern part of the township.

In Montgomery township till and bowlders in moderate amount appear at Santa Fé, and are continuous north ten miles to Cloverdale.

Till, with abundant granitic bowlders, also covers the highest hills in the northeastern corner of Morgan township, and three miles to the southwest.

In Lafayette township the deposits of till are thin, but extensive throughout the northwestern half. Three miles south-southwest of Vandalia, striæ were found running up hill nearly east and west in the outcropping sandstone strata. Five miles to the west, in Marion township, well-defined striæ were found running S. 40° to 50° E.

Till appeared in the northeastern corner of Jefferson township, and for three miles to the southwest; but there was none in Franklin township.

*Greene County.*—From Switz City, westward, no glacial deposits appear for four miles; but they begin to be seen in Stockton township, and are continuous to the western border of the county, being from fifteen to twenty feet in depth. Scratched pebbles and granitic bowlders are abundant.

*Sullivan County* is completely enveloped in till.

*Knox County.*—East of Vincennes, on rising from the broad gravel terrace of the Wabash, and one and a half miles from it, sand-hills rise about one hundred feet. A mile farther on, hills rising one hundred feet are covered with loess, which completely envelops everything. But in Harrison township, seven miles southeast from Vincennes, cuts of fifteen or twenty feet through the loess revealed an irregular deposit of true till. The hills are here from one hundred to one hundred and fifty feet above the valleys, but the depth of the till could not be ascertained.

*Daviess County.*—Nothing like till was found in the southern part of Daviess County in a drive from Washington to Petersburgh, Pike County.

*Gibson County.*—At Princeton, Patoka township, there is a deposit of till thirty or forty feet deep, with granitic pebbles, one of which was a foot and a half through. There were also numbers of striated pebbles in this bank. Loess, ten or twenty feet deep, covers rounded slate hills to the east. No granite pebbles were to be found in the eastern part of Princeton township and the western part of Columbia.

At Owensville, Montgomery township, loess is everywhere on the surface, with blue till underneath containing granitic and scratched pebbles. Till also appears at Fort Branch, in the southern part of

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Patoka township. Wells are reported as penetrating red and blue clay 20 feet. Eastward to Barton township no glacial material could be found.

*Vanderburgh County.*—Extensive detours in Vanderburgh County disclosed everywhere the loess resting upon the rocks in place, and the streams utterly devoid of gravel.

*Posey County.*—Robb township, in its eastern part, is so deeply enveloped in loess that the character beneath could not be determined. The hills are about two hundred feet above the Wabash (estimated). In the northwestern corner of the township, facing the valley of Black Creek the loess is underlaid by till, which is certainly 20 feet deep. Scratched stones and granitic bowlders were numerous. This exposure continues for a mile and a half. Black Creek, which flows through this deposit, contains much granitic gravel. Granitic pebbles and striated stones occur also on the hills between Black Creek and the Wabash.

One-half mile southeast of New Harmony a section shows 15 feet of loess overlying till of an unknown depth, but with no sharp line of demarcation between them. The trough of the Wabash is here about five miles wide.

### ILLINOIS.

The glacial boundary in Illinois (see Plate V) first appears in White County near Phillipstown, and bears in a general southwesterly direction through Gallatin, Saline, and Williamson Counties, whence it bears northwest through Jackson, Randolph, and Monroe Counties, forming the east border of the Mississippi bottom-lands. But nowhere in this region are the glacial deposits thrown into ridges and hills as in the Eastern and Northwestern States, and they are everywhere buried, to a greater or less extent, by loess.

*White County.*—At Phillipstown the bluff facing the Wabash bottoms, opposite New Harmony, Ind., shows from twenty to thirty feet of till at the bottom, merging gradually into loess of about the same thickness. One-half mile west, compact blue till, containing fragments of rock and small bowlders, appears at 10 feet below the surface.

Hawthorn and Emma townships are an extensive sandy plain not more than twenty or thirty feet above the Little Wabash.

Throughout Carmi and Heralds Prairie townships till with all its characteristics everywhere appears under the loess on the west bank of the Little Wabash. A characteristic section in the southwestern part of Heralds Prairie gives 11 feet of loess and 35 feet of till. No sharp line of demarcation between the two could be found. Granitic bowlders 5 feet through occur in Carmi township. Mr. James Chilton reported a nugget of copper as found in section 28.

*Gallatin County.*—In Gallatin County glacial deposits are found only in Bear Creek, the northwestern township, where at Omaha station a considerable deposit occurs with granitic pebbles three or four inches through, which gradually merges into the loess above, and is reddish

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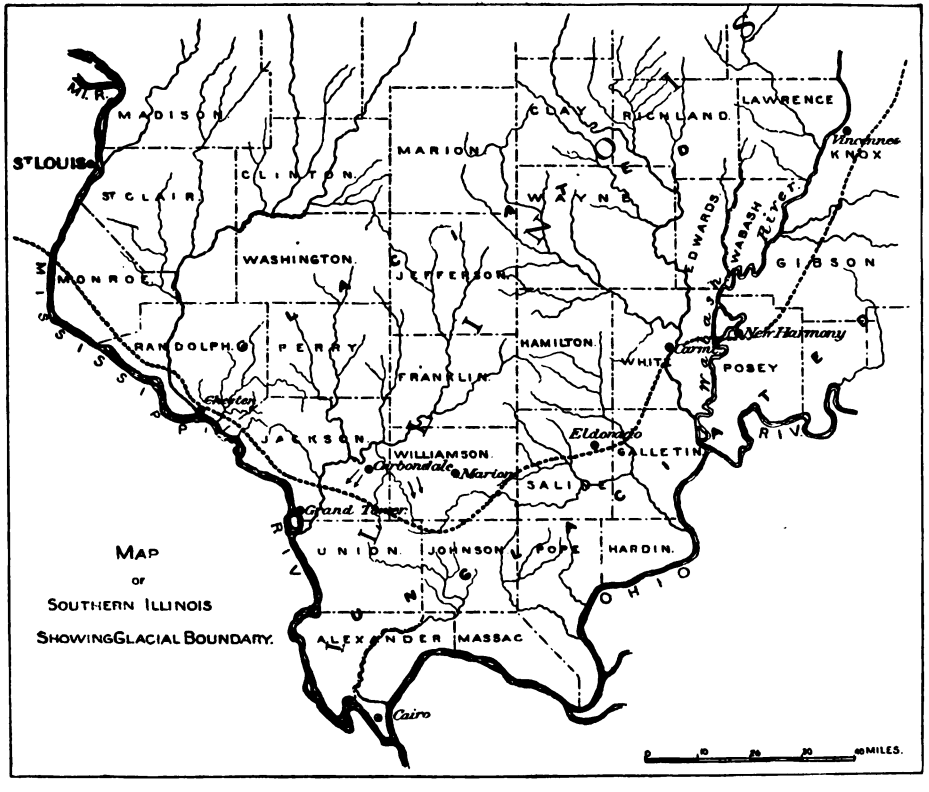
MADISON
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EDWARDS
WABASH
RIVER
GIBSON
MONROE
RANDOLPH
PERRY
HAMILTON
WHITE
New Harmony
POSEY
FRANKLIN
Chester
JACKSON
WILLIAMSON
Eldorado
GALLATIN
Carmi
Carbondale
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Grand Tower
UNION
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MAP
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in color. A detour to Shawneetown, and thence to Equality, disclosed no clearly marked glacial deposits.

*Saline County.*—Just north and west of Eldorado station, and 75 feet (barometer) above it, till, red in color, is exposed similar to that at Omaha, Gallatin County, but is absent to the southeast.

Till is abundant on the road from Eldorado to Raleigh. The soil is red, and the granitic pebbles are much decomposed. At Raleigh the loess is more of a yellow cast.

An extensive detour in Harrisburg township disclosed no glacial marks. The loess was more red in color.

Numerous exposures of till at least ten feet deep appear in the northern sections of Brushy township. Granitic bowlders two feet through are frequent. This is south of the Middle Fork of Saline River, the bottom-lands of which are about fifty feet below the general level.

*Williamson County.*—Till six to ten feet deep with the same amount of loess overlying, is exposed at Attila (120 feet above Marion). A similar deposit appears throughout the eastern part of Crab Orchard township. Striated stones are abundant. A trap-bowlder, two and a half feet, was observed. The color of the loess was yellow; the depth from five to ten feet.

At Sarahsville is an exposure of till covering several acres. Sections show 10 feet of loess, then 20 of till, in which are granitic bowlders two and a half feet in diameter. The material is of various colors, red, orange, and yellow, and without stratification.

Deposits similar to that at Sarahsville continue to Creal Spring and Sulphur Spring, 200 feet above Marion, but they cease near the line of Johnson County, reappearing farther west on recrossing the Williamson County line.

Till is abundant in the southern portion of Grassy township, but disappears just before crossing the Union County line (at an elevation of 400 feet above Carbondale). In section 30, near the southwestern corner of the township, is a half acre of till like that at Sarahsville, where, on the sand rock exposed underneath, are distinct striæ already referred to (p. 42) as the most southern point in America at which striæ have been observed east of the Mississippi.

*Jackson County.*—Deposits of till are frequent in the northeastern and northern part of Makanda township, but do not extend to the higher lands in Union County. A striated surface was uncovered near the road, one and a half miles southwest of Carbondale; direction of striæ, S. S. 5° W. This is in section 29, Carbondale township. The covering of till removed was from eight to fifteen feet.

Ridge township contains a fine exposure of till with abundant granitic pebbles, from six to eight inches in diameter, in section 1, T. 10 S., R. 1 W. From ten to fifteen feet of till is overlaid by the same amount of loess (165 feet above Carbondale). There is no till in the southern and central portions of the township, which is exceedingly rocky and

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rough, though loess from ten to twenty feet is everywhere found; but till appears in the nortwestern portion of the county in sections 5 and 8, T. 7 S., R. 4 W. (360 feet above Carbondale). Two miles west from this point the rocky bluff descends perpendicularly to the Mississippi, about four hundred feet below.

*Randolph County.*—The hill back of Chester (310 feet above the river) is covered very deeply with loess, in some places 100 feet. No till was observed within the city limits, but granitic pebbles were found in gulleys (210 feet above the river) north of the city. At Welga station, five miles back from the river, till abounds in great quantities with frequent granitic and striated bowlders two feet in diameter. A fresh section here shows six to ten feet of loess, graduating rather suddenly into a gravelly stratum about ten feet in thickness resembling true till, resting upon soil filled with local fragments.

The contour of the country seems to have been largely determined by the direct glacial deposits, as the loess rested like a blanket of pretty even thickness over all, adjusting itself to previous irregularities.

### MISSOURI.

A detour through Missouri from opposite Grand Tower to Perryville and to the river bank opposite Chester, Illinois, disclosed no sign whatever of glacial action, though everywhere there is a covering of loess, the general elevation being 300 feet above the river. The river valley all along is from five to seven miles wide.

*Jefferson County.*—Extensive detours in Jefferson County disclosed no true glacial phenomena there.

At De Soto (300 feet above the river) there was no loess on the hills, but everything was covered with a red residual clay full of local fragments.

*St. Louis County.*—West from Carondelet station there are no hills much more than 100 feet above the river, and all are covered with a blanket of loess about 20 feet deep. Sections show that this sometimes rests upon the unevenly eroded surface of the limestone, but sometimes also upon a thin stratum of well-rolled gravelly soil with an occasional granite pebble, but nothing like till was discovered.

Between Carondelet station and the business part of St. Louis, on the turnpike, numerous quarries and sink-holes, about one hundred and fifty feet above the river, show at the bottom of the loess a stratum of red clay a foot or more thick, containing granitic and other pebbles up to three inches in diameter. The depth of the loess is about twenty feet.

Near Forest Park, on the road to Ferguson, a section shows loess about 20 feet, with gravel from two to three feet at the bottom containing granitic and finely striated pebbles two or three inches in diameter. I found similar sections also near Hyde Park. This gravelly stratum was extensively uncovered in 1883 near the brick yards in the neighborhood of Shaw's Botanical Garden. Here many granitic and striated

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pebbles were found. The upper terrace of the limestone was much eroded, and the gravelly stratum rested directly upon it. No striæ was discovered upon the limestones in place, but thin fragments of limestone striated upon one surface were found. This is three miles back from the river (elevation about one hundred and fifty feet).

### GENERAL REMARKS.

The Illinois Central Railroad from Chicago to Cobden, in the southern part of the State of Illinois, discloses but few glacial phenomena of interest to the transient traveler, though southward from Mattoon the color of the soil in the deeper cuts seems to be more distinctly red than to the north. The surface is covered with a fine, light colored silt, compact and without gravel and from one to two feet thick. Below is a reddish clay of undetermined depth, containing fine gravel of chert, quartz, limestone, and granite.

At Centralia sections fourteen feet deep showed white clay, three to five feet, with tough yellow clay containing quartz pebbles below. At Ashley a section of twelve feet showed two feet of white clay without grit, graduating into yellow clay containing an increasing amount of fine gravel with bowlderets and striated fragments lower down. At Du Quoin wells from seventeen to twenty feet in depth have two feet of loess with three to four feet of gravelly soil, with many striated and granitic pebbles lower down. Fragments brought up from the rock in place were striated. In Cobden, seven miles south of the glacial limit (and 350 feet above Carbondale) there is no loess and there is no sign of glaciation; but there is much compact clay (see specimens 34 and 35).

At this point it will be profitable to give a more summary and explicit statement of the form of the glacial deposits over the glaciated margin traversed between the Alleghanies and the Mississippi River. As before remarked (page 55), a distinct, continuous terminal moraine along the southern margin of the glaciated region is not easily traced west of the Delaware River. Across the State of Pennsylvania the marginal accumulations worthy to be called a moraine (that is, consisting of knobs and ridges of any considerable height with inclosed kettle-holes), are found only at infrequent intervals, as already described (pp. 55–57). West of Pennsylvania such marginal accumulations are still more infrequent. The only places in the whole distance of the marginal belt surveyed between Pennsylvania and the Mississippi River in which I have encountered the features of a terminal moraine, such as exists south of New England and across the State of Wisconsin, are suggested, are the following:

In Columbiana County, Ohio, extensive ridge accumulations are found near Palestine on the eastern edge of the county, on one of the branches of Little Beaver Creek. These ridges were evidently formed by streams of water which issued into the valley from the ice-front, and in their composition resemble kames. In the western part of the county, at New Al-

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exandria, upon the higher land in the county, and about 3 miles back from the border of the glaciated region, the deposits of till are as much as 50 feet deep, and are marked in a moderate degree by the knobs and kettle-holes characteristic of a true moraine.

In Stark County, next west, ridged accumulations of great size (85 feet high) with large kettle-holes occur within a mile of the extreme border of glaciation. These ridges are on a scale which compares favorably with the Kettle Range in Wisconsin, and the material, like that of the Kettle Range, is pretty largely water-worn. (See above, p. 60.)

In Holmes County, though the glacial margin is sharply defined, and the glacial deposits are of considerable depth over the whole northern part of the county, there are no ridged accumulations of marked size except in the valley of the Killbuck, a few miles above Millersburgh. (See above, p. 60.)

In Knox County no extensive ridged accumulations were anywhere observed, though the depth of the glacial deposit is considerable down to within a short distance of the margin.

In Licking County in the vicinity of Wilkins Run, in Mary Ann township, there is an extensive marginal accumulation of terraces and kames, some of which are 92 feet high. A little farther to the south, also in Newark township, and very near the marginal line, the glacial deposit is marked by small hummocks and ridges at an elevation of 200 feet above the valley. In the southeastern part of Licking township, near the reservoir, there are extensive kame-like ridges from 15 to 30 feet above the level of the valley, which here drains through Jonathan Creek into the Muskingum. To what extent the base of these ridges is covered by deposits of loam and peat could not be ascertained.

Thorn township, Perry County, presents in its northern part a continuation of the phenomena in Licking township just described. The reservoir occupies a kettle-hole on the water-shed between a branch of Licking River and Jonathan Creek.

In Fairfield County the glacial limit is marked by ridges and hummocks of till at least 50 feet in depth, on the east side of Rush Creek. This is on land 200 feet above the valley. At Berne station there are hills of gravel from 50 to 60 feet in height brought down by the streams which drain the glaciated area in Pleasant township. In Hocking and Madison townships of this county the accumulations of till are very marked, being in some cases 40 feet in depth, at a height of 450 feet above the Hocking River, at Lancaster. Muddy Prairie, so-called, seems to be an immense shallow kettle-hole very near the margin.

In Ross County, at Adelphi, in the northeastern corner of the county, near the head of the valley of Salt Creek, the marginal accumulations are more marked than anywhere else in the State. Here, on the east, facing Salt Creek, they show a perpendicular section of 188 feet, and extend southwesterly through Colerain and Green townships, for sev-

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eral miles to the Scioto Valley. The knobs, ridges, and kettle-holes are marked at various places within a mile of the southern limit of glacial signs. In Green township, on the eastern edge of the Scioto bottoms, kame-like ridges of gravel rise from 100 to 150 feet above the general level. West of the Scioto, at Lattas, in Concord township, ridges and knobs from 50 to 60 feet in height are numerous, resting on the flanks of the hill which faces to the northwest. The ice, however, surmounted this hill (which is about 400 feet above the general level to the north), and extended 3 or 4 miles, reaching the narrow valley of Paint Creek, in which, near the junction of Cat Tail Run, there are immense kame-like accumulations.

In Pike County the depression in the col between Bainbridge on Paint Creek and the headwaters of Baker's Fork of Brush Creek is filled to an indefinite depth by deposits of till, showing numerous ridges, knobs, and kettle-holes. This is on the extreme margin, and is about 200 feet above the bottom-lands of Paint Creek, and is flanked on the south by a level-topped loess deposit, extending for 2 or 3 miles. (For a fuller description of this, see pp. 92–96.)

Through the southeastern corner of Highland County and the northwestern of Adams, the terminal accumulation is less marked than in Ross County; still the boundary of the glaciated region can be readily determined. In neither of these counties, nor in Brown or Clermont Counties, were there any ridged accumulations which could be properly called moraines, and I think that the same is true of Clinton County, and also of Hamilton, though the till is from 10 to 20 feet deep in the neighborhood of Walnut Hills station in Cincinnati, and 350 feet above the river, while at North Bend a preglacial channel extending from the Miami to the Ohio is filled by till to a height of 160 feet.

In Indiana the glacial deposits in the glaciated portion of Jefferson, Clarke, and Scott Counties are comparatively scanty. The deposit is much deeper over Dearborn, Ripley, Decatur, Jennings, and Bartholomew Counties, but though I traversed them in every direction, I nowhere encountered in them any ridged accumulations which properly could be called moraines. In Johnson County, however, where the boundary approaches the higher lands of Brown County, ridges and knobs of till were encountered in two or three places, and to some extent in the western part of Morgan County, but nothing of the sort appeared in Owen, Clay, Greene, Sullivan, Knox, White, Gibson, and Posey Counties.

In Illinois nothing like a moraine was encountered in any portion of the State which I traversed, which included Randolph, Perry, Franklin, Jackson, Williamson, Saline, Gallatin, and White Counties.

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## HYPOTHESIS OF A GLACIAL DAM AT CINCINNATI.

### INTRODUCTION.

From the facts already stated it seems evident that the ice of the glacial period came down to the north bank of the Ohio River all the way from Brown County, Ohio, to Madison, Indiana, a distance, as the river runs, of more than one hundred miles, while it is equally clear that at points south of Cincinnati glacial ice extended across the river into Kentucky from six to ten miles. The acceptance of this conclusion raises some most interesting questions in speculative geology. The interpretation of the facts will depend upon whether the glacial deposits upon the north and south sides of the Ohio River belong to the same period or to different periods widely separated in time. The question also involves that as to whether the deposits upon the south side of the river were made before or after the Ohio had worn its present valley.

Upon the supposition that the long, narrow trough of the Ohio River (described on p. 57) was preglacial, the glacial deposits upon the south side at Cincinnati imply an ice dam between five and six hundred feet in height. Such an obstruction in the present condition of the valley would set the water back so as to submerge Pittsburgh to a depth of about three hundred feet, and affect the Alleghany River as far up as Oil City, and the Monongahela nearly up to Grafton, West Virginia.

Soon after the first announcement of these facts[1] Prof. I. C. White published a paper upon the terraces of the Monongahela River, which seemed to him in a remarkable degree to confirm the theory of an ice dam at Cincinnati.[2] To judge of the value of these individual facts it is necessary to take a more comprehensive view of the whole matter than has heretofore been possible, and to speak somewhat in detail of the terraces throughout the whole valley of the Ohio and its tributaries.

### THE LOWER TERRACES OF THE OHIO AND ITS TRIBUTARIES.

The valley of the Ohio River above Louisville is characterized by two sets of terraces, the lower of which is very persistent throughout the whole course and is especially developed wherever tributaries from the glacial region enter it. So uniform is the increase in the height of a terrace in the Ohio Valley immediately below the mouth of its tributaries, coming from the glaciated area, that there can be no hesitation in attributing their deposition to the vast flow of water down these tributaries into the Ohio during the period in which the ice extended into their headwaters. The deposits in the Ohio below the mouth of Big

[1] Am. Jour. Sci., 1883, 3d Series, vol. 26, p. 326.

[2] See Proc. Am. Assoc. Adv. Sci. 32d (Minneapolis) meeting, 1883, p. 212, and The Glacial Boundary in Ohio, Indiana, and Kentucky, G. F. Wright (Western Reserve Historical Society), 1884, pp. 81–86.

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Beaver Creek in Pennsylvania, are typical of what elsewhere occurs, and may therefore be described with considerable minuteness.

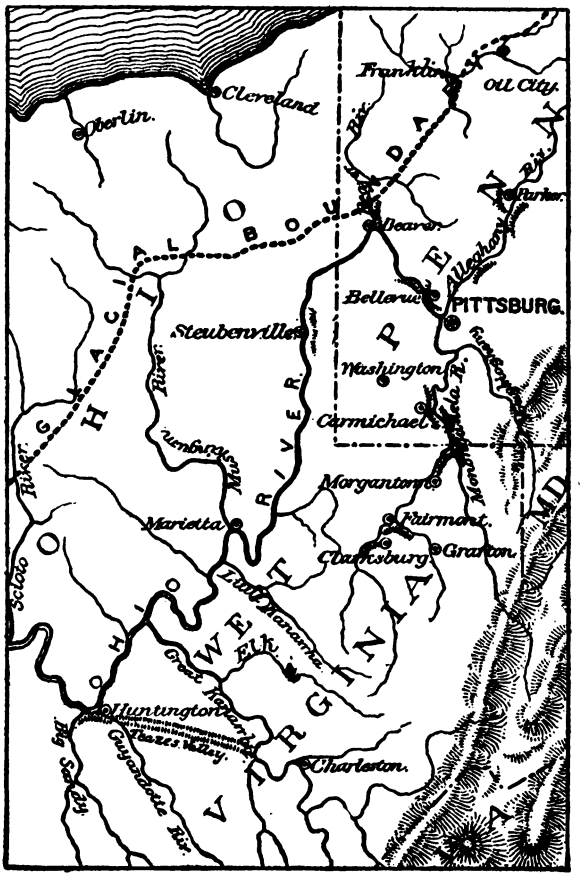


FIG. 4.—Map of the tributaries of the upper Ohio.

The towns of Beaver and Rochester, Pennsylvania, are built upon a terrace which is 120 feet above the level of the Ohio and but eight or ten miles south of the glaciated region. The composition of that part of the terrace occupying the terrace upon which Beaver is built, and down stream from the junction of Beaver Creek and the Ohio, differs remarkably from that upon which Rochester is built, on the angle up stream from the junction. In the angle below the junction of the streams the terrace is composed of rounded pebbles of quartzite, gneiss, and granite, some of them, even near the surface, being two feet in diameter. In the angle above the junction granite pebbles are exceedingly rare, and pebbles of any kind more than two or three inches in diameter are scarce. The explanation is evident. To use Prof. Dana's terms when speaking of the Connecticut River and the White River,[1] the Ohio is the great *distrib-*

[1] See Am. Jour. Sci., 3d Series, vol. 22, 1881, p. 466.

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*uter* and the Beaver is here the principal *contributor*, of drift material. The Ohio does not itself have direct access to the bowlders which had been transported by glacial ice, it being wholly outside of the glaciated region. The drainage basin of the Beaver is, however, strewn with glacial débris down to within a few miles of the Ohio; and, as the granite bowlders of that area were borne along by the swollen torrents at the close of the glacial period, on reaching the onward but less rapid current of the larger Ohio they would naturally be deposited at the junction of the streams and in the lower angle.

The one hundred and twenty to one hundred and thirty foot terrace, upon which the city of Beaver is built, continues upon the north side of the Ohio River downward to Vanport, two miles, where it crosses to the south side and continues below to Raccoon Creek. Here it reappears upon the north side and continues to Six Mile Run, reappearing upon the south side a little above Industry. From Industry down three or four miles it is again upon the north side, reappearing on the south side one mile from Georgetown, two miles from the Virginia line, where, according to my leveling, it is 112 feet above the river, and contains numerous granitic bowlders two feet or more in diameter. It is evident that the whole valley from Beaver to Georgetown, 14 miles, was once filled with coarse gravel and pebbles to a height of about one hundred and twenty feet, the material being much coarser at Beaver than at Georgetown. A well-marked terrace, also containing granitic pebbles, is found on Little Beaver Creek, one mile from its mouth, and 130 feet above the Ohio.

Below the mouth of Little Beaver Creek, as far as Marietta, at the mouth of the Muskingum River, there is no tributary entering the Ohio which could have been charged with glacial floods or with glacial material. There is, therefore, as might be expected, a gradual but marked diminution below this point in the extent of the terrace deposits. At Steubenville the extensive terrace upon the east side, according to my measurement, is but 95 feet above low water, and at Martin's Ferry, opposite Wheeling, the extreme height of the terrace is 102 feet. In both these places the granitic pebbles are numerous, but are smaller than higher up the river. From Martin's Ferry to Marietta I have not examined the banks of the river. This increase in the height of the terrace was remarked by Sir Charles Lyell,[1] who estimates it as 60 feet high at the mouth of the Great Kanawha, and about eighty feet high at Georgetown.

The Muskingum River, which enters the Ohio at Marietta, is lined with terraces all the way up to its headwaters in the glaciated region. It was therefore an important contributor to the glacial drift of the Ohio. Consequently at Rockland, about twelve miles below Marietta, and where the Ohio turns at right angles to the west, we find a marked increase in the glacial terrace. Blennerhasset Island is but fifty or sixty

[1] Travels in America, second series, vol. 2, p. 224.

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feet above low-water mark, and is occasionally completely submerged by floods. The terrace at Rockland, however, is nearly 50 feet above the present high-water mark. About five miles below, opposite Little Hockhocking, a terrace appears again upon the south side of the Ohio, corresponding in general elevation and character to that at Rockland on the north side. The terrace at Ironton is 90 feet, while at Portsmouth, below the mouth of the Scioto, another chief contributor of glacial drift, the terraces on both sides are 110 feet.

There are no other specially marked terraces at any considerable distance above the present high-water mark until reaching Cincinnati, just below the mouth of the Little Miami River, which was one of the most abundant contributors of drift material from the glaciated region. Here we find the upper terrace, upon which the main part of the old city of Cincinnati is built, to be about fifty feet above the present high-water mark, or 120 feet above low water. Twenty miles below, at Lawrenceburgh, Indiana, near where the Ohio is joined by the Great Miami (another most important contributor from the glaciated region), the terraces rise to 112 feet above low-water mark, or about eighty feet above the flood plain. The terraces here are of equal height upon both sides of the Ohio; but upon the west side are much broader, extending into the valley from one-fourth to three-fourths of a mile from the foot of the bluff. The valley itself between the bluffs is here about three miles wide. Farther down the river the upper terraces are of diminished height. At Warsaw, Kentucky, about 20 miles below, the highest terrace is ninety feet above low water, or about thirty feet above high water. At Madison, Indiana, 20 miles still farther down, the upper terrace is 85 feet above low water. From these facts it is evident that there is no need of supposing the Ohio Valley to have been filled up through its entire course with gravel to the height of the terraces where the streams enter from the glaciated region. But just below the mouth of each of those streams there was an excessive deposit, which formed a bar or slight dam, as is the case now in the Mississippi at the mouth of its present tributaries. The Ohio, then, at the close of the glacial period, would have presented a series of long pools, one stretching down to the vicinity of the mouth of the Beaver, where the water must perceptibly have shoaled for several miles. A second pool ended at Marietta, at the mouth of the Muskingum; a third pool extended to the mouth of the Scioto at Portsmouth; a fourth to the vicinity of Cincinnati. Below the mouth of the Great Miami there was no contributor of glaciated material to obstruct the channel with its excessive deposits until reaching the mouth of the Wabash. There can be no question that this series of high terraces belongs to the closing stages of the last glacial epoch, if there were two epochs. The present flood plains are deposited in a channel which has been worn out of these larger deposits of the glacial period. And, as already noted, these glacial terraces are but parts of a still deeper de-

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posit filling an old preglacial channel which was one hundred and fifty or two hundred feet deeper than the present trough.

All the southerly flowing streams which rise in the glaciated region are marked at the points at which they enter the unglaciated district by terraces of exceptional height (but never exceeding 160 feet), containing many granitic pebbles, and gradually diminishing, both in height and in the size of the pebbles, as they recede from the glacial boundary. Such terraces are specially noticeable at the following localities:

In Pennsylvania, on the Delaware River, at Belvidere; on the Lehigh River, at Bethlehem; on the Susquehanna, at Berwick; on Fishing Creek, below Benton; on the Loyalsock, above Montoursville; on Lycoming Creek, below Ralston; on the Conewango, below Ackley Station; on Big Broken Straw Creek, at Spring Creek; on Oil Creek, at Titusville; on French Creek, above Franklin; on Big Beaver Creek, at Chewtown.

In Ohio, on the middle fork of Little Beaver, at New Lisbon; on the east branch of Sandy Creek, a tributary of the Tuscarawas, at East Rochester; on the Nimishillen, just below Canton; on the Tuscarawas, near Bolivar; on Sugar Creek, another tributary of the Tuscarawas, at Beech City and Deardoff's Mills; on the Killbuck, another branch of the Tuscarawas, below Millersburgh; on the Mohican, above Gann's Station; on the Licking, at Newark; on Jonathan Creek, near Thornville (the last eight all empty eventually into the Muskingum); on the Hocking River, at Lancaster; on the Scioto, a few miles above Chillicothe.

In Indiana, on the east fork of the White River, at Seymour, and on the Wabash, near New Harmony.[1]

### THE UPPER TERRACES OF THE OHIO AND ITS TRIBUTARIES.

Disconnected with the lower set of terraces, there is another, which is far more difficult of interpretation, and which stands at a much higher level. We will note the places where this upper set of terraces is most conspicuous, beginning below Cincinnati and going towards the source of the river.

I am inclined to reckon, as belonging to this series of upper-terrace formations, the conglomerate (described on page 64) near Woolper Creek, a few miles above Belleview, in Boone County, Kentucky, and 25 miles below Cincinnati. What is here known as Split Rock is but a dismembered portion of a level-topped terrace of cemented gravel rising 185 feet above low-water mark, and extending back from the river from one-half to three-quarters of a mile, and a mile or two along the sides of the valley. A deposit precisely similar occurs a mile and a half back from the river, near the headwaters of Middle Creek, about three hundred and fifty feet above low-water mark.

[1] For fuller information on this subject, see Am. Jour. Sci., July, 1882, pp. 8–14; Geol Survey, Ohio, vol. 5, pp. 761–762.

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I am inclined also to classify with the upper terraces some cemented gravel containing granitic pebbles, and similar to this at Split Rock, found on Bracken Creek at its junction with the Ohio just above Augusta, Kentucky, about fifty miles up the river from Cincinnati. The summit of this is about two hundred feet above low-water mark. The pebbles of the conglomerate are very coarse, and numbers of them are granitic and from three to four inches in diameter. A similar conglomerate occurs upon the opposite bank, near Higginsport, Ohio.

Going up the river, an instructive remnant of the higher terrace was found on the east side of the Ohio River a little below Steubenville, Ohio, opposite the lower ferry, and about twenty miles above Wheeling, West Virginia. At this point the representative of the lower terrace previously described is about one hundred feet above low-water mark, and is well developed. But farther back from the river, upon the West Virginia side, numerous granitic pebbles occur at an elevation of 50 feet higher, and included in an extensive deposit of sand, whose upper limit is 285 feet above low-water mark, or about one hundred and eighty-five feet above the lower terrace. Just to the north of this point the rocks in places project to the river's bank, at an elevation of four or five hundred feet above the river; thus during excessively high water favoring the formation of the deposit just described.

The remnants of the upper terrace below Steubenville correspond both in general character and in elevation above the river to three others between the mouth of Beaver Creek and Pittsburgh, of which one is at New Brighton, on the east side of the Beaver not far from its junction with the Ohio. Here there are remnants of a terrace preserved upon a rocky shelf and containing many rounded pebbles of granite 215 feet above the Beaver, and 260 feet above the Ohio. This is several miles outside the extreme limit of direct glacial action. The pebbles are at the bottom of a thin deposit of cream-colored clay which is used for brick-making.

A similar terrace exists back of Middletown, Alleghany County, on the south side of the Ohio River, 12 miles below Pittsburgh. Here, at the height of from two hundred and fifty to two hundred and eighty feet above the river, rolled fragments are abundant; and among them an occasional pebble of granite.

A third noteworthy remnant of a terrace between the mouth of the Beaver and Pittsburgh occurs at Bellevue, in Ohio township, Alleghany County, Pennsylvania, on the north side of the Ohio, about five miles below the mouth of the Alleghany River.[1] Here, upon a shelf of rock facing the river, in a perpendicular cliff, between two hundred and fifty and three hundred feet in height, there is the remnant of a terrace whose surface is 310 feet above low-water mark and containing many granitic pebbles. This terrace is about half a mile in width. A well

[1] See I. C. White, 2d Geol. Survey, Pa., Q. p. 175.



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sunk from the surface was reported to me as passing through 20 feet of tough clay and 25 feet of sand, coarse gravel, and quicksand, showing pebbles at the bottom a foot or more in diameter. At that level springs come out facing the river. Facts concerning analogous terraces on the Monongahela are detailed in the next section.

### THEORETICAL EXPLANATIONS.

Here we may well pause to consider the theoretical elements of the problem, and ask, by what combination of forces known to be in operation could this terrace of gravel at Bellevue, which incloses pebbles of northern drift, be deposited nearly three hundred feet above the present level of the Ohio River, and 1,000 feet above tide? The granitic pebbles must by some means have been brought down the Alleghany River from as far up as Franklin, a distance of 125 miles. To account for this terrace and some others which I shall presently mention, there are only three possible hypotheses, each involving in some form the aid of the glacial theory. These hypotheses are (1) that during or since the glacial period the whole region of the upper Ohio passed through a period of subsidence, the limit of which is marked by these upper terraces; (2) that there has been some local obstruction like that of the supposed Cincinnati ice dam; (3) that the upper terraces were formed during an earlier glacial epoch when the rocky beds of the streams occupied a higher level than now.

That these upper terraces are coincident in date with, or subsequent to, a glacial epoch is clear from the fact that the granitic elements entering into their formation could have been brought into the headwaters of the Alleghany River only by a movement of glacial ice from the distant north. After being left by glacial ice in this region, they were within reach of streams of water which could transport them an indefinite distance towards the Gulf of Mexico. Such granitic pebbles from the glaciated region are, at the present time, transported by flowing water far down the Ohio River, and even into the Mississippi. But, whether rolled along upon the bottom or transported upon floating ice, they can now be deposited along the stream only to the height of the present flood-plain, which is nowhere more than seventy feet above the bottom. The present problem is how to account for them in terraces 300 feet above the river.

### THE UPPER TERRACES THE REMNANTS OF A DISTINCT GLACIAL EPOCH EARLIER THAN THAT PRODUCING THE LOWER.

There is no question but that these facts may be accounted for on the theory that there have been two glacial epochs, in each of which the ice extended into the headwaters of the Alleghany; and that these high terraces were formed during the first glacial period, as the present flood-plain of the river is formed, but when the bed of the river was between two and three hundred feet higher than it is now. This, how-

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ever, would involve the supposition that sufficient time elapsed between the first glacial period and the second for the Ohio and its tributaries to wear down their channels through their rocky bed, and along their whole length to a depth of between three and four hundred feet. If we accept without question the theory of two glacial periods so nearly equal in extent and separated by such a vast interval of time, this is the easiest way to account for the facts as so far presented.

But without questioning the fact of two distinct glacial epochs, we may question the propriety of accounting for this terrace by a glacial epoch so far back in time as this theory supposes. From the Falls of the Ohio at Louisville, Kentucky, to the head of the Alleghany, for a distance of about one thousand two hundred miles the stream has lowered its bed through the rocks to a depth of more than four hundred feet below the bottom of the terraces in question. For the testimony is unequivocal that the rocky bottom of the Ohio River from the Beaver down is not far from two hundred feet below its present bottom. The time necessary for this amount of erosion is enormous.

### FACTS ADVERSE TO THIS THEORY.

Now, there are many facts which would seem to forbid such an enormous lapse of time between the deposition of these upper terraces containing granitic pebbles and the formation of the lower terraces containing similar material, as before described. In the first place, vegetable and animal remains of recent species are found in a very fresh state of preservation in river deposits of the Ohio Valley corresponding in age with the upper terraces in question.

*Terraces on the Monongahela.*—The first instance has been carefully described by Prof. I. C. White, and occurs on the Monongahela River, near Morgantown, West Virgina. The trough of the Monongahela, which joins the Alleghany at Pittsburgh to form the Ohio, is in every way similar to that of the Alleghany, with the single exception that the terraces which line its banks at heights corresponding to those of the Alleghany and the upper Ohio, contain no pebbles of northern drift but consist wholly of material which is native to the valley itself. At numerous places, as Professors White [1] and Stephenson have pointed out along the Monongahela, and as I myself have since observed, there are extensive deposits of pebbles and bowlders from two to three hundred feet above the river, especially near where the tributaries enter. Many of these deposits may well enough be regarded as the river pebbles left in the channel when it flowed on a rocky bottom two or three hundred feet higher than at present. Such places may be noted at Belle Vernon, Brownsville, and Masontown, in Fayette County, Pennsylvania, and Greensborough, in Greene County, Pennsylvania. But, in the opin-

[1] See The Glacial Boundary in Ohio, Indiana, and Kentucky, G. F. Wright (Western Reserve Historical Society) pp. 82–84.

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ion of Prof. White, the deposits near Morgantown, West Virginia, can not be so easily explained in this manner. I transcribe Prof. White's description, premising that his familiarity with the region is greater than that of any other competent observer.

In the vicinity of Morgantown, terraces of transported material occur at the following approximate (measured by barometer) elevations:

| Terraces. | Feet above river. | Feet above tide. |
|---|---|---|
| First | 30 | 820 |
| Second | 75 | 865 |
| Third | 175 | 965 |
| Fourth | 200 | 990 |
| Fifth | 275 | 1,065 |

The first terrace is the present flood-plain of the river, consisting principally of fine sand, mud, and gravel. * * *

All of the other terraces have thick deposits of transported material, wherever the original contour of the surface has favored its preservation from erosion. From the top of the fourth terrace Mr. Keck dug a well through seventy feet of clay, gravel, and bowlders without finding bed rock. He also encountered logs of wood in a soft or semi-rotten condition near the bottom.

Many other wells on the third terrace have been sunk to depths of 20 and 30 feet without reaching bed rock. * * *

Owing to the considerable elevation—275 feet—of the fifth terrace above the present river bed, its deposits are frequently found far inland from the Monongahela, on tributary streams. A very extensive deposit of this kind occurs on a tributary one and a half mile northeast of Morgantown, and the region, which includes three or four square miles, is significantly known as the "flats." The elevation of the "flats" is 275 feet above the river, or 1,065 feet above tide. The deposits on this area consist almost entirely of clays and fine sandy material, there being very few bowlders intermingled. The depth of the deposit is unknown, since a well sunk on the land of Mr. Baker passed through alternate beds of clay, fine sand, and muddy trash to a depth of 65 feet without reaching bed rock. In some portions of the clays which make up this deposit, the leaves of our common forest trees are found most beautifully preserved. Whether or not they show any variations from the species growing in that region the writer hat not yet had time to determine, but when a larger collection has been obtained, this subject will receive the attention that it deserves, since if the date of the glacial epoch be very remote, the species must necessarily show some divergence from the present flora.

Of animal remains the only fragment yet discovered in this highest of terraces is the tooth of a mastodon, dug up near Stewartstown, seven miles northeast from Morgantown.

More recently Prof. White[1] contributes other interesting facts which concern the terraces farther up the Monongahela, and which can best be quoted in this connection:

Owing to the nature of the topography, and the country rock along the draining streams, the region along the upper Monongahela has these terrace deposits in better preservation than any other with which the writer is acquainted, and this is especially true of the West Fork branch of that stream. It is along this line that the existence of a great submergence which covered the country with a thick coating of

[1] Am. Jour. Sci., 3d series, vol. 34, 1887, pp. 378, 379.

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transported material up to a certain level, is most conclusively shown. In the region of Morgantown, on the main Monongahela, these terrace deposits end at about two hundred and seventy-five feet above low water, or 1,065 feet above tide, while at Fairmount, 26 miles above, there is a vast amount of this terrace material thrown down about the junction of the Valley and West Fork Rivers, and the upper limit of the same is a little over two hundred feet above low water, which is here 850 feet above tide.

About twenty miles farther up the river (West Fork), near Shinnston, the upper limit of the terrace material is found at 160 feet above the water, but here the latter has an elevation of about eight hundred and eighty-five feet above tide.

At Clarksburgh, where the river unites with Elk Creek, there is a wide stretch of terrace deposits, and the upper limit is there about one thousand and fifty feet above tide, or only 130 feet above low water (920), while at Weston, 40 miles above (by the river), these deposits cease at 70 feet above low water, which is there 985 feet above tide. It will thus be observed that the upper limit of the deposits retains a practical horizontality from Morgantown to Weston, a distance of 100 miles, since the upper limit has the same elevation above tide (1,045–1,065) at every locality.

These deposits consist of rounded bowlders of sandstone, with a large amount of clay, quicksand, and other detrital matter. The country rock in this region consists of the soft shales and limestones of the Upper Coal Measures, and hence there are many "low gaps" from the head of one little stream to that of another, especially along the immediate region of the river, and in every case the summits of these divides, where they do not exceed an elevation of 1,050 feet above tide, are covered with transported or terrace material, but where the summits go more than a few feet above that level, we find no transported material upon them, but simply the decomposed country rock.

A fine example of one of these bowlder-covered divides may be seen at the mouth of the Youghiogheny River, back of McKeesport, Pennsylvania. The "divide" in question is one between the waters of Long Run, which puts into the Youghiogheny two miles above McKeesport, and that of another little stream which heads up against it, and flows into the Monongahela within the city limits. The divide between these two water-ways, although 275 feet above the level of the river, is almost imperceptible in a broad and bowlder-covered valley through which there is not the slightest doubt that the waters of the Youghiogheny once flowed during the epoch of submergence.

Another typical illustration of these terraces in the valley of the Monongahela occurs at Carmichael's, Greene County, Pennsylvania. Carmichael's is about five miles west of the river and (as shown in the accompanying map) about the same distance from an angle in the stream which it makes in turning to the north. The village is built on what is called the "Glades," which extend about two miles in one direction and three in the other. The Glades are about two hundred and fifty feet above the river, and from one to two hundred feet below the general level of the country, and are connected by a pretty well defined channel at about the same level with the river both above and below. Above, this old river channel is continuous with one on the east side near Masontown—the two old channels forming a sort of a double ox-bow in the reverse direction from those in the present bed of the stream, and about two hundred and fifty feet above it. The whole course of this old channel is marked by rounded pebbles, such as are found at the bottom of the present river, and these are covered more or less with several feet of loam. The glades at Carmichael's are simply an enlargement in this old channel. But at Carmichael's a log of wood

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was reported to me as found buried 30 feet in the sand. Much quicksand is found from 15 to 20 feet below the surface. It hardly seems possible that wood should have been preserved in such a situation during all the immensely long period required for the river to lower its bed through the rock to its present level. Many of the river pebbles may belong to the earlier period, but after eliminating the effects of that early cause it is difficult to resist the conviction that most of the fine loam and quicksand, together with the buried wood, belong to a much later period of deposition. It is easy to see that with the water standing at about that level throughout the whole valley, wood and clay and sand would come down from the higher reaches of the river and be deposited in such sequestered places. Any cause that can be shown to have acted in recent times to raise the water to that level will furnish the most natural explanation of the facts.

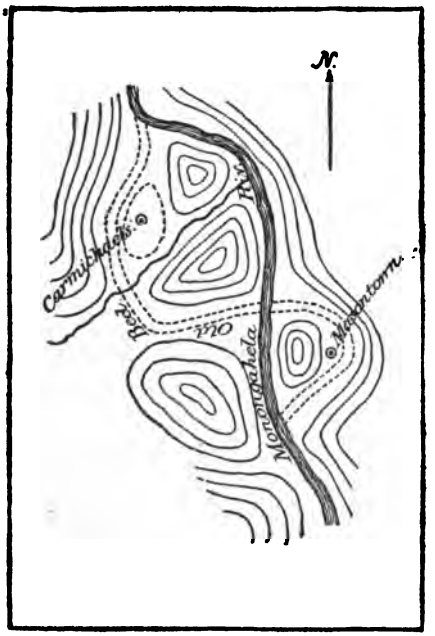


FIG. 5.—Map of the old channel of the Monongahela, between Masontown and Carmichael's, Virginia.

Wood has been found also in a similar situation in the remarkable terrace on the Alleghany River, near Parker, Pennsylvania. Here also there is a sort of a double ox-bow at a level of about two hundred and fifty feet above the present bed of the river. But, unlike the gravel at Carmichael's, the gravel here is partly composed of granitic pebbles, though far outside of the region of the direct action of glacial ice. Like that at Bellevue, on the Ohio, this gravel bears unmistakable evidence of having been deposited during the glacial period. The wood was reported as dug from quicksand in a well two miles east of the Alleghany, near the eastern limit of the high deposit containing the pebbles just mentioned. It should be noted, however, that the absolute level of this deposit at Parker is somewhat higher than that at Bellevue, but it scarcely differs at all from that of the fifth terrace described by White as extending from below Morgantown, West Virginia, to Clarksburgh.

*River deposits in Teazes Valley, West Virginia.*—Still another instance of wood which has been preserved in a deposit of the glacial age is worthy of minute description. In this case I have the advantage of having found it myself. The locality to which we are now transferred is that of Teazes Valley, Putnam County, West Virginia. This valley runs

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from the Kanawha River, a little below Charleston, to the Ohio at the mouth of the Guyandotte, near Huntington. The valley is clearly enough a remnant of early erosion, when the water of the Upper Kanawha took that course to join the Ohio. The valley is very clearly

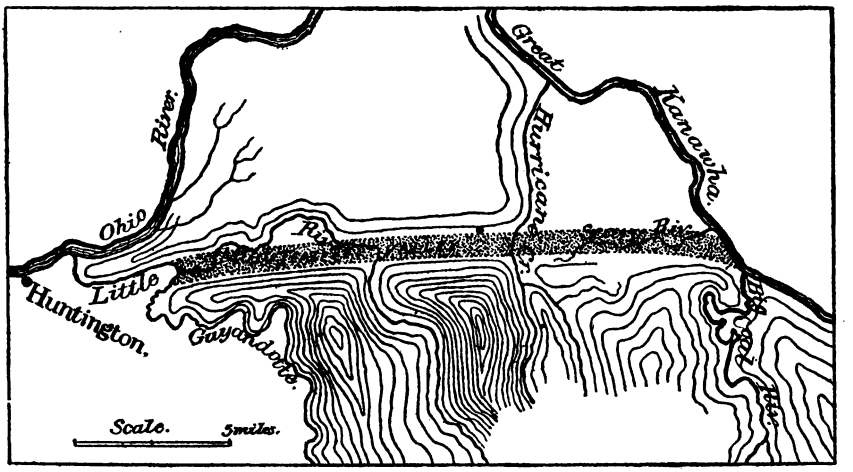


FIG. 6.—Map of Teazes Valley, West Virginia.

marked, being about a mile wide and from two to three hundred feet lower than the hills on either side, and having a remarkably level floor throughout the greater part of its course. The bottom of the valley is filled throughout with a deposit of river pebbles covered many feet deep with a mixture of sand and clayey loam. (See Plate VI.) In some places this loam is from thirty to forty feet deep, extending for several miles without interruption, as at Long Level, about the middle of the valley. Here a section about one-half mile long and 25 feet deep shows at the top a stiff stratum of clay containing wood at a depth of seven feet. Immediately below is sand containing much iron and cemented together by the infiltrations of the ore. The stratum above containing the wood had never been disturbed, and the wood, a small specimen of a knot of some coniferous tree, is remarkably fresh in its whole appearance. It is scarcely possible that it should have remained in such a position during all the time required for the erosion of the Ohio Valley and its tributaries from the level of Teazes Valley to its present level, 250 feet below. Besides, there are many other things going to show that the deposit was in slack water rather than on the banks of a running stream. Unlike the deposits of a river on its banks, in this case the silt extends clear across the valley, covering everything to a uniform depth, except where it has been removed by subsequent irregular erosion. A single cut in this silt, shown in Pl. VI, is one-half mile or more in length.

Another evidence of the recent date of this deposit of river silt as compared with the erosion of the valley, appears in the relation of the

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transverse valleys to it. Mud River and Hurricane Creek are two small streams rising some little distance to the south of the valley, but now either joining or crossing it at a level sixty or seventy feet lower than that of the rocky bottom of the valley (see map of Teazes Valley). Mud River joins the valley at Milton, and then turns west and follows its course to the Guyandotte. But its level even above where it now joins the valley is 120 feet lower, and this a channel worn in the solid rock. Hurricane Creek is a still smaller stream, and crosses the valley within a few miles of its eastern end, emptying into the Kanawha some miles farther down. Where it crosses the Teazes Valley its bed is sixty or more feet lower down in the rock than that on which the pebbles and silt rest throughout the valley, and these deposits come down on the rocky shelf bordering the Hurricane in a way to show that it could not have remained where it is during the time required for so small a stream to wear down so extensive a channel.

The old river valley in Boyd County, Kentucky, back of Ashland, is really a continuation of Teazes Valley, which then continued down as far as opposite Hanging Rock, just below Ironton, Ohio. It was the river pebbles in this part of the old valley, just back of Ashland, which deceived some of the earlier observers, and led to the impression that there were signs of the actual presence of glacial ice in this county in Kentucky. On close examination, however, it appears that the pebbles are all regular river pebbles, and moreover are all from the valley of the Kanawha. Especially there is to be noted a dark-colored flint peculiar to the mountains of West Virginia.

*Terraces on the Big Sandy.*—But wood is not the only perishable material whose preservation is significant. Pebbles of the soft sandstones of the coal measures are almost equally perishable, and Prof. I. C. White reports accumulations of these at various points at high levels on the southern tributaries of the Ohio. One such instance is on the right bank of the Big Sandy, 10 miles above its junction with the Ohio. Here Professor White[1] has described a deposit of rounded and flattish bowlderets from two to four inches in diameter and 450 feet above the stream (950 above tide). "These rounded bowlders of local coal measure sandstone [in the opinion of Prof. White] could hardly have resisted the elements during the long time since the Big Sandy Valley existed at this 400-foot level."

The hill on which they occur is a topographical summit for the immediate vicinity so that this does not represent the highest deposits of such a nature in the region. A similar deposit occurs on the Guyandotte, at the mouth of White Oak Creek, where a bed of bowlders was observed by Prof. White extending up to 150 feet above the river, or to 925 above tide.[2]

*Terraces on the Elk River.*—A still more significant collection of such

[1] Am. Jour. Sci., 3d series, vol. 34, 1887, p. 375. [2] Loc. cit.

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SECTION OF DEPOSIT NEAR HURRICANE, IN TEAZES VALLEY, WEST VIRGINIA.

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material near the junction of the Elk with the Kanawha is thus described in a communication to me by the same experienced observer:

Where the Kanawha meets the Elk at Charleston, West Virginia, a great bed of bowlder trash extends to 225 feet above the river (780 feet above tide), among which are large numbers of metamorphic rocks from the Blue Ridge region of Virginia. Many bowlders go much higher, while some extend to 390 feet above the river, or to 945 feet above tide.

One of the best pieces of evidence for the glacial dam that I have found, outside of Teazes Valley, may be seen a short distance up the Elk River, at the summit of the divide separating the waters of two small streams, which both empty into the Elk thus:

Here we find a deposit of clay, bowlders, and other trash on the summit of the divide, and how it could have got there except from backwater of some kind covering the surface there I am at a loss to understand.

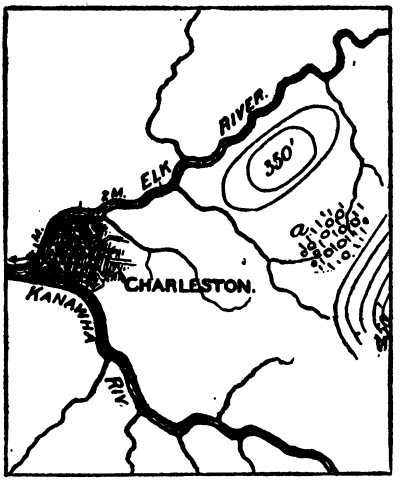


FIG. 7.—Outline map of Elk River, West Virginia.

Another instance of possibly still greater significance has been reported by Professor White since the above was in type. It occurs on the water-shed between the west branch of the Monongahela and Middle Island Creek, which empties into the Ohio some distance above Marietta. The Parkersburgh branch of the Baltimore & Ohio Railroad makes a cut in this summit about fifteen miles west of Clarksburgh, West Virginia. There is here "a broad level summit, having an elevation of 1,100 feet, in a gap of probably 300 feet below the inclosing hills. That gap, or valley, is covered by a deposit of fine clay. The cut through it is about thirty feet, and one can observe the succession of clays of all kinds and of different colors, from yellow on the surface down to the finest white potters' clay at the level of the railway where the cut reaches bed-rock, thus proving that the region has been submerged." This submergence would carry a water-level up the Alleghany Valley so as satisfacorily to explain the phenomena there attributed by some to a first glacial epoch. Speaking of the theory of President Chamberlin, that all these deposits in the Monongahela Valley were connected with the formation of the benches which slope downward, and were the result of erosion, Professor White claims "that subsequent to the erosion of these benches all of them were covered with lacustrine deposits. The proof of this is found in the fact that along the Monongahela and its tributaries there is at the summit of this lacustrine level a deposit of clays and bowlders and erosion debris of every description, beginning at 1,100 feet above sea-level and extending down to the present flood-plain. Now, on the Baltimore and

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Ohio Railroad (at the point before described) there is, it seems to me, an absolute proof of this submergence, because the old valley slopes there on the one hand into the Ohio and on the other into the Monongahela, and yet the summit has 30 feet of a clay deposit, and on this summit, and on other tributaries of the Monongahela, these clay deposits cease at altitudes of 1,075 to 1,100 feet, and above that level there is no deposit—there is simply the decomposed shale and rocks in place. Why should these clay deposits cease near that prescribed level if there has been no submergence during the later history of this valley?"[1]

*Terraces in Bath County, Kentucky.*—Mr. G. H. Squier has also furnished me facts of a similar character concerning deposits in the upper portion of the valley of Licking River, Kentucky. In Bath County he found over an extensive region of low table-land, between Slate Creek and Licking River, and for some distance to the north, large numbers of water-worn pebbles, composed of white quartz, chert, black shale, and sandstone, and, most remarkable of all, fragments of water-worn coal. These are spread, not over the low table-land and in the valleys, but over the lower hills; but do not extend vertically as high as the watershed. The pebbles of sandstone and coal must have been brought down the streams at least twenty miles, and it is evident that they could not have been left upon this table-land and these low hills by running water They are just such deposits as would occur during the existence of a temporary lake into which floating ice from the east could bring and deposit the materials in the situations indicated.

It may seem an insuperable objection to the foregoing theory of an ice dam, that at Oil City there is a terrace in the fork of the Alleghany with Oil Creek, which is 325 feet above the river, and that granitic pebbles appear in this. The low-water mark in the river at Oil City is about nine hundred and sixty feet above tide, which would make the elevation of this terrace 1,285 feet above tide. Also at Tidioute, about thirty miles farther up the river, glacial terraces are found on both sides of the river at just about the same absolute level. The solution of this difficulty may be found, on this theory, by supposing another ice dam in the Alleghany, at Franklin, Pennsylvania, and direct evidence of such an obstruction is not wanting. On reexamining the region with a view to correcting the glacial boundary as originally laid down by Prof. Lewis and myself, I found abundant evidence that former suspicions as to the incorrectness of our inferences were amply justified, and there can be no doubt that glacial ice at one time covered the hills down to the Alleghany River both above and below Franklin. Both above and below the angle of the Alleghany at that point I found granitic bowlders and scratched stones at elevations of from four to five hundred feet from the river, and farther east than the western angle of the river.

[1] Bulletin of the Geological Society of America, vol. I, pp. 477–479.

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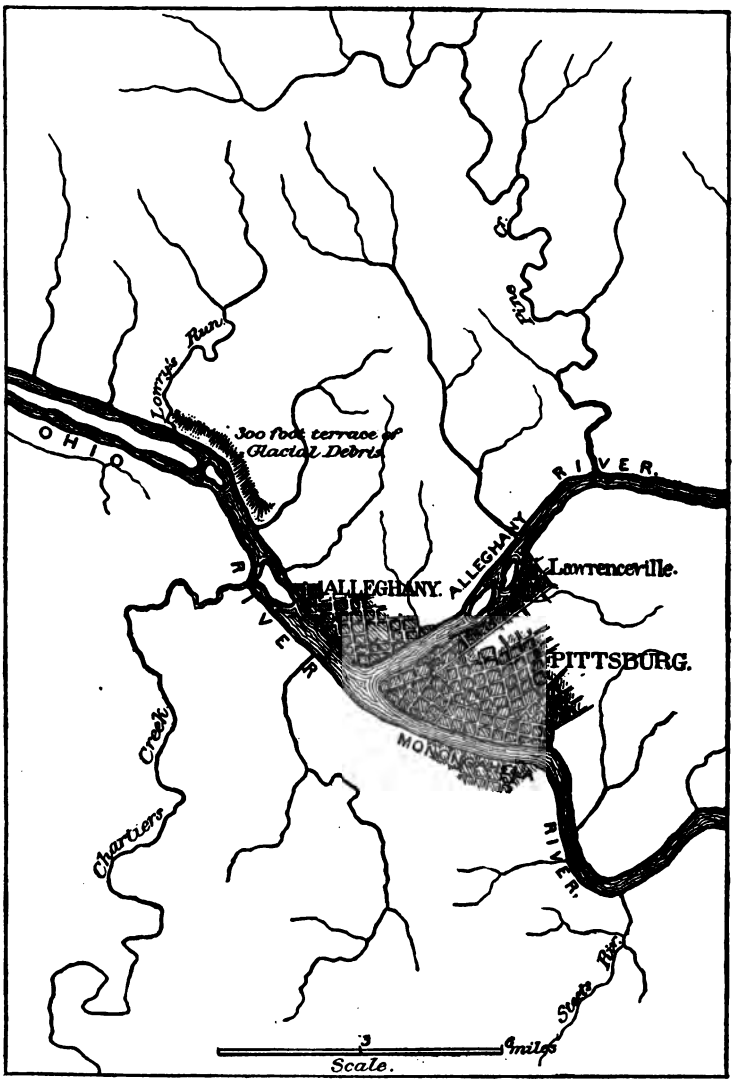


FIG. 8.—Map showing terrace at Bellevue, Pa., and the relation of Chartiers Creek to the Alleghany River.

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*Beech Flats, Pike County, Ohio.*—Another crucial case is to be found in Pike County, Ohio, at the headquarters of Brush Creek. By reference to the accompanying map it will be seen that at the height of the glacial period the front of the ice rested at the northwest corner of Pike County, and that the divide between Paint Creek and Baker's Fork of Brush Creek is formed by the extreme portion of the direct glacial deposits. Before the glacial period there was a continuous depression connecting Paint Creek with the valley of Brush Creek, though not suffi-

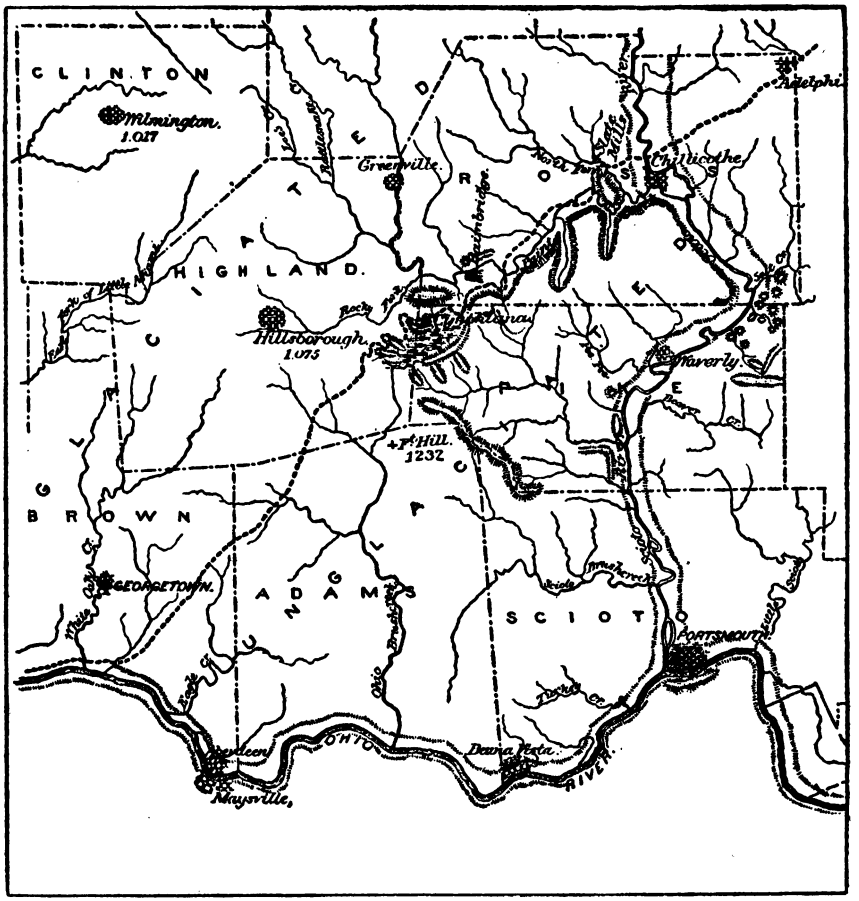


FIG. 9.—Map showing the still-water deposit between Paint Creek and Brush Creek, southern Ohio.

ciently low to make it the line of drainage. At a point about five miles south of Bainbridge, on Paint Creek, this depression is filled up, from side to side, to a height of about two hundred feet, with a true glacial deposit containing numerous northern bowlders and scratched stones. On the northern side, towards Paint Creek, this deposit exhibits every mark of a terminal moraine, with its characteristic knobs, ridges, and kettle-holes; while to the south of it there is an extensive plain, known

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in the locality as the "Beech Flats." This, too, consists largely of transported material from the north; but it is level topped, and is considerably higher than the valley of Baker's Fork, which heads in it and runs to the south, emptying, finally, into the Ohio River. Its elevation is about nine hundred and fifty feet above tide.

The significance of this condition of things cannot be fully apparent without a discussion of the remarkable facts connected with the valley of Paint Creek between Bainbridge and its junction with the Scioto River. From examination of the map it will appear that the course of this creek below Bainbridge is in a northeasterly direction, parallel with and along the very margin of the glacial boundary. The valley of the creek is here about a mile wide, and is bounded on either side by steep banks leading up to the table-lands about five hundred feet above the stream. We cannot, as yet, be certain whether during the glacial period the ice extended to the southeast side of this valley for several miles below Bainbridge or not. But, as Prof. Orton[1] long ago pointed out, the preglacial outlet of Paint Creek was certainly for a time completely obstructed by ice. This preglacial outlet continued onward in a northeast direction till it was joined by the North Fork, at Slate Mills (shown on the map), where it turned to the right and pursued its course through a broad valley to join the Scioto below the present site of Chillicothe. It appears at a glance that, while the ice during the glacial period occupied the northeastern end of the valley, in the vicinity of Slate Mills, the drainage was compelled to seek a more southern outlet. A visit to the locality also makes it evident that after the ice had withdrawn, glacial deposits in that part of the valley presented a barrier to the occupation of its former channel by Paint Creek, compelling it to seek an outlet by a cut-off across a point of the table-land extending up to Slate Mills from the south. The evidence that Paint Creek has occupied this cut-off only since the glacial period appears primarily in the fact that the narrowness in that part of the gorge is in striking contrast to the other portions of the valley. It has not had time to enlarge as other portions of the valley have. Whereas other portions are about one mile wide at the bottom, this is not over 500 feet.

As before remarked, the table lands are here about five hundred feet above the valley of Paint Creek, and are built up of parallel strata of soft shale underneath and Waverly sandstone on the surface, the shale occupying here much the larger portion of the perpendicular height. It was Prof. Orton's opinion that this cut-off was formed by the action of the water which flowed along the front of the ice while it closed the lower part of Paint Creek Valley, in the vicinity of Slate Mills, and it has even been suggested that this might serve as a measure of the length of time during which the ice-front remained at this point, the problem being how long time would be required for the formation of

[1] Second Geol. Survey, Ohio, vol. 2, pp. 653–655.

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such a gorge in such strata, the distance being in the neighborhood of two miles, and the strata being favorable to rapid erosion.

But, upon further examination and more mature reflection, it seems to me doubtful whether that can with certainty be called in its whole extent a postglacial gorge. The little stream seen upon the map to enter the cut-off at its southern angle is in itself an eroding agency of considerable importance, having worn back since the glacial period a tributary gorge no less than 600 feet in length; so that it is by no means impossible that the whole gorge across the promontory may have been formed by this and perhaps another stream flowing one to the east and the other to the west. If this cut-off had been thus formed in large part before the glacial period, then but a very short time would have been required to scour out the shale in the lower part of its bed, so that the extensive glacial deposits in the vicinity of Slate Mills should permanently turn the stream through the cut-off, where it now flows. As the result of my last visit to the locality, I am inclined to place the glacial boundary a little south of the cut-off, and make it follow the southeastern side of Paint Creek Valley up to Bainbridge. At any rate I have found granitic pebbles on the table-land for some little distance south of the cut-off.

My notes report that not only granitic but occasionally scratched pebbles were found upon the farm of Mr. A. T. Long, in Huntington township (400 feet above the level of Paint Creek), and that one sandstone fragment two feet in diameter was distinctly striated. More extensive deposits of gravel containing granitic pebbles were found at a level 150 feet lower than Mr. Long's farm, on either side of the water-shed between the creek above the cut-off and the creek below the cut-off, and from one-half to one mile distant, and all about one mile south of the cut-off. These deposits can be explained only in two ways. Either the ice extended upon the highlands one mile south of the cut-off (which is the more probable hypothesis) or water stood at that level while the ice-front was in the vicinity. As to the causes which might be supposed to have kept the water at that level, I will speak a little later.

Recurring now to the deposits south of Brainbridge, their true significance can be made to appear. Beech Flats is evidently a still-water deposit, for it is nearly level topped, slanting but gently to the south; it penetrates the side valleys for two miles south of the moraine-like deposits; it is of fine material like the loess; it is of considerable depth, being eroded by small streams in many places so as to show from ten to twenty feet in depth of homogeneous material; it ceases rather suddenly on the southern side, though there is no obstruction in that direction. No such deposit could have taken place in that position if there had been a ready outlet to the water down the valley of Brush Creek, for the valley does not materially contract in dimensions towards the south, and the descent, all the way to the Ohio River, is rather rapid, being not less than from six to ten feet to the mile. It follows that if the valley

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had been open, a body of water large enough to have produced this loess deposit of which Beech Flats is constituted would have produced a torrent down Brush Creek of sufficient rapidity and size to have transported gravel and pebbles far down its course, forming terraces in that stream as in the other streams emerging from the glacial boundary. But there are no such terraces. In going three times over the field for several miles to the south, I looked in vain for any granitic pebbles along the stream.

Putting the facts connected with Beech Flats with those connected with the Paint Creek cut-off, near Chillicothe, there would seem to be but one adequate explanation, namely, the production of slack water (at a level from 900 to 1,000 feet above tide) by some such temporary obstruction as I have supposed in the Cincinnati ice-dam. This would permit a level-topped deposit of fine material immediately in front of the moraine, such as exists in Beech Flats, and would prevent the transportation of overwash gravel down the valley open in ordinary circumstances along Brush Creek. That at that time no line of drainage could have been opened through the Paint Creek cut-off is also evident from the facts presented. The main work of erosion through the Paint Creek cut-off, indeed, may have been, and probably already had been, accomplished in preglacial times by small streams. But the creek itself had doubtless continued in its original channel until the ice from the north reached Slate Mills, when the obstructed water must have begun pouring through the cut-off, and must have rapidly completed the work of erosion already well advanced by the work of the smaller streams. But if, as we have seen reason to believe, the ice continued to extend until it had passed the cut-off, so as to deposit the striated pebbles found on the farm of Mr. Long, one mile south of the cut-off, the outlet through this channel must for a time have been obstructed, and as there is no other lower place till reaching Cynthiana, the drainage ordinarily passing through the mouth of Paint Creek was turned into Brush Creek, when, if the way had been open, there would have been produced a torrent as in other valleys similarly situated.

But if one is not willing to grant that the granitic and striated pebbles to the south of the cut-off were deposited by an extension of glacial ice, but would maintain that these were carried thither by floating ice, he has still the problem of accounting for standing water at that level (not less than 1,000 feet above tide) on the Scioto side of the projecting table land as well as on the Paint Creek side. These deposits one mile to the west of Mr. Long's farm (on the southeast side of Paint Creek Valley and 250 feet above it) and similar deposits farther up the valley might at first seem to be the result of the more local ice-dam at the mouth of Paint Creek. But when considered in connection with the similar gravel deposits one-half mile to the east, in the watershed drained by Rolston Creek, which empties into Paint Creek below the cut-off, it seems more likely that both of them are to be connected with

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the same cause, and that this cause is the one which produced the slack water in which Beech Flats were formed. Thus we seem to have in this fortunate combination a crucial test of the hypothesis in question, in which the conditions are met in every important particular.

The theory is further confirmed by the fact that the lower portion of Paint Creek is so situated with reference to the glacial boundary that when the ice-front at this point had withdrawn but two or three miles, as it would very likely do contemporaneously with the withdrawal of ice from Kentucky, an ample outlet for glacial drainage would be opened into the Scioto 200 feet lower than the surface of the moraine between Paint and Brush Creeks; so that the natural necessity for a glacial outlet down Brush Creek would exist only so long as the ice closed up the mouth of Paint Creek. Just as soon, therefore, as the ice had retreated from the Kentucky hills south of Cincinnati so as to raise the blockade, and reopened the channel of the Ohio, it would doubtless also have retreated from the mouth of Paint Creek, and the line of glacial drainage through that into the Scioto and thence down the reopened Ohio would have been reestablished.

A theory which will so naturally account for so complicated a set of facts as these is well-nigh proved by this single instance. The only competing theory possible is that of a general subsidence of the country producing the same water level above Cincinnati which the ice-dam is supposed to have done. But this theory lacks such positive evidence as we have for the glacial dam at Cincinnati, and besides, it is not probable that a general depression of the country such as would produce still water at the head of Brush Creek would be of such short duration as is implied by the facts connected with this deposit, since any such general cause of obstruction would have been likely to reverse its action slowly, and so would have given time for the formation of numerous benches on the interior of the deposit toward the ice, whereas the terrace on that side is even more abrupt than on the other.

*Freshness of the vegetable remains near the glacial margin.*—The question of the occurrence of such an immense interglacial period as is implied in attributing the high level terraces just mentioned, as well as the glacial deposits in Boone County, Kentucky, to a first glacial epoch entirely distinct from that which covered the most of the area marked as glaciated, can not be settled without considering carefully the deposits of wood and peat found near the margin in widely separated localities all along the line.

One of the most instructive localities in which to study these deposits is in the region included in southern Montgomery and Butler Counties, Ohio. These deposits were first described by Prof. Orton, of the Ohio survey, in 1870.[1]

The most considerable deposit is found near Germantown, on Twin Creek, in Montgomery County, about thirty miles north of Cincinnati.

[1] Am. Jour. Sci., 2d ser., vol. 50, 1870, pp. 54–57.

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SECTION OF PEAT AND DRIFT, GERMANTOWN, OHIO.

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Here at a sharp angle of the stream there is exposed a perpendicular bank of drift 95 feet in height. Underneath this is a deposit of peat as much as 14 feet thick. The upper portions of the peat "contain undecomposed sphagnous mosses, grasses, and sedges." Both the stratum of peat and the clayey till above contain "abundant fragments of coniferous wood, which in many instances can be identified as red cedar (Juniperus virginianus)." (For the structure of the bank see Plate VII.) The composition of the drift deposit above the peat is as follows: Immediately above the peat there is from fifteen to twenty-five feet of true till. This has no sign of stratification, and abounds in striated stones. Next above occurs a band about ten feet thick of stratified material containing coarse gravel and a good deal of fine sand. Above this to the top the deposit is again true till, with, however, an occasional pocket of sand or thin layer of stratified material. But, both up the stream and down it, the cut terminates to appearance in vast gravel beds cemented together. Down the stream the stratum of peat rises so as eventually to come in contact with the band of stratified material before mentioned, the intervening till meanwhile gradually thinning out between them. The appearance is that of a saucer-shaped deposit of peat, such as would form in a kettle-hole, and which was subsequently filled and covered over with the advance of the glacier.

Whether it is necessary to interpret these facts as indicating two entirely distinct glacial ages or not will naturally be a matter open to dispute. That the facts indicate a somewhat prolonged interval between the first advance of the ice over the region and the second, can not well be denied, for the peat is clearly enough between two glacial deposits. But it may be well questioned whether an interval of a few hundred years would not suffice for the accummulation of the peat and the growth of the large cedar trees which, without doubt, flourished in that region immediately in front of the readvancing ice, and were rather suddenly overwhelmed by it. At any rate, the other localities in which fragments of wood are found imbedded in the till would show that there was not any great difference either in the conditions or the time of the first and second advances of the ice. Some of these other facts will now be noted.

The most extensive exposures of till containing woody fragments are in Butler County, Ohio, a few miles southwest of the deposit described above. One of these, near Darrtown, on Four Mile Creek, has already been spoken of on page 63. Upon reference to the description there the course of events would seem to have been as follows: A temporary retreat of the ice occurred, during which, for a short time, water was active in depositing material over the lower stratum of till, then there was a readvance in which a vast mass of unsorted material was pushed along over the stratified stratum without disturbing it. Above Germantown, in the bank described in the preceding paragraph, I thought I discovered as many as four such marks of successive advances



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and retreats. Pl. VIII shows a section of till on a tributary of Four Mile Creek, near Oxford, Butler County, a few miles only from Darrtown. In this the unstratified character of the deposit is sufficiently manifest, and a piece of wood well preserved is seen projecting from the perpendicular exposure of the bank. This is about forty feet below the surface, and is where no land slide could have occurred. Equally good sections were afterwards seen in the same county on Aunt Ann's Run, near the city of Hamilton.

The wood in the instances next mentioned is found still nearer the glacial margin and they are of such a character and so numerous as to connect the previous instances with a glacial movement extending to very near the extreme margin of any signs of the direct action of glacial ice.

It is reported to me that a sycamore log was found at Morgantown, Morgan County, Indiana, 30 feet below the surface. This is, however, in a stratified deposit, but one which was evidently formed in connection with the last stages of the glacial period at that point. It is one-quarter of a mile back from the little creek running through the village, and the glacial limit is but a few miles south, on the higher lands of Brown County.

Near Seymour, Jackson County, Indiana, logs of wood are reported as occasionally found in digging wells in the village at a depth of 20 feet below the surface. Seymour is on a glacial terrace in the line of Collett's glacial stream, which was supposed to flow just east of the highlands in Brown County, and southward towards Jeffersonville. The wide terrace on which Seymour stands, and in which the logs are found, is about sixty feet above the present bed of the east fork of White River, running through the place. Black walnut logs are also mined from the banks of the river in low water. This instance is probably not decisive of the age of the buried wood, as the terrace may be the product of the so-called second glacial period. All agree that one of the later forward movements of ice in the interior came down as far as the northern border of Brown County.[1]

Other most decisive instances occur in Bigger township, in the southeastern corner of Jennings County, Indiana. Here, as already said,[2] wood occurs in one well 12 feet deep in true till, while near by wood was reported to me as found 30 feet below the surface in a well that failed to reach the rock at that depth. This is on as high land as there is in that region, and is about ten miles north of Madison, on the Ohio River, and about five hundred feet above it; and the signs of glaciation are abundant over the whole region. The well reported by Professor Borden,[3] at Paris Crossing, in Jennings County, as containing wood in blue drift clay 40 feet below the surface, is about twelve miles southwest of

[1] Preliminary paper on the Terminal Moraine of the Second Glacial Epoch by T. C. Chamberlin, Third Annual Rept. U. S. Geol. Survey, 1883, p. 333.

[2] See page 67.

[3] Seventh Annual Report Geological Survey, Indiana, for 1875 (1876), p. 172.

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SECTION OF TILL SHOWING WOOD, ONE MILE SOUTH OF OXFORD, BUTLER COUNTY, OHIO.

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the foregoing place. That at Milan, with muck and wood 54 feet down in what is evidently the true till of the region, is near the summit of Ripley County, Indiana, and is as far south as Cincinnati, and about twelve miles northwest from the river.

In Hamilton County, Ohio, Col. Charles Whittlesey reports thirty-five wells containing muck beds, leaves, or timber, from 300 to 500 feet above the Ohio River.[1] That at New Burlington is certainly in till.

In Highland County, Ohio, Prof. Orton reports many cases of the occurrence of such vegetable deposits. In the village of Marshall "eleven wells out of twenty reached a stratum of vegetable matter, with leaves, branches, roots, and trunks of trees." Marshall is on the very limit of glaciation. Similar instances were reported to me in the southern part of Highland County and in Clermont County.

In Ross County, near Lattas, Mr. J. M. Connell reported to me finding wood in a well on his farm. This is situated very near the extreme limit of glacial action, and is where it could not have been brought into position by water action. Mr. Connell's farm is 425 feet above the valley at Frankfort, two miles to the north, and 525 feet above the valley of the Scioto River at Chillicothe, 10 miles to the east. The till is massed up in great quantities against and upon the margin of the rocky plateau, here facing the north. The well described was in this marginal till upon the highest land, and passed through 12 feet of yellow clay, then through three or four feet of blue clay, then 10 feet of yellow clay, then gravel for five feet. About thirteen feet below the surface there was found a log of wood three or four feet long, and about three inches in diameter. This was in blue clay, and was accompanied with traces of muck.

I have omitted to mention many other places where wood is reported in what are perhaps preglacial channels serving as outlets to the south of the melting torrents, and which may have been transported a long distance from their native place. One such was reported to me in the valley of Raccoon Creek in Granville, Licking County, Ohio, and but a few miles from the glaciated border. This was found 94 feet below the surface of the terrace, which would bring it about forty feet below the present bed of the stream. A few miles farther up in this same valley red cedar logs were formerly found in great numbers beneath what I inferred were the glacial terraces along the valley; and the wood was so fresh that a flourishing business was for awhile carried on in manufacturing them into pails. Red cedar is not found growing in that region now, and the logs were evidently of the same period with those described as found in true glacial till in Butler County.[2]

Prof. Collett reports that all through southwestern Indiana there are found from 60 to 120 feet below the surface, peat, muck, rotted stumps, trunks, branches, and leaves of trees, and that these accumulations

[1] See Smithsonian Contributions for 1869, pp. 13, 14. [2] See above, p. 63.

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sometimes occur through a thickness of from two to twenty feet. One mile west of Switz City, in Greene County, Indiana, a hickory log was reported to me as found 20 feet below the surface, but according to my observations, this was a short distance outside of the glaciated limit, and may have been of recent origin.

## SUMMARY.

It will be profitable at this point to take a rapid survey of the facts bearing on the theory of a glacial dam at Cincinnati.

(1) The deposits in Kentucky south of the Ohio River, in Boone and Campbell Counties, seem to be such that only glacial ice could have deposited them. This being granted, the question then comes whether this extension of glacial ice took place before or after the erosion of the trough of the Ohio River. Bearing on this question we note that—

(2) The freshness of the glacial deposits in Hamilton County immediately north of the river, together with the perfectly preserved specimens of wood just enumerated from till in Jefferson and Ripley counties, Indiana, and in Butler, Hamilton, Clermont, and Highland Counties, Ohio, would seem to indicate that they belonged to a period much less remote than that when the Ohio was flowing in a rocky bed from three to four hundred feet higher than that now occupied. And it is scarcely probable that a second general glacial period, separated so far from the first, would be so nearly coincident in extent with the first as it must have been if the deposits south of the river belong to the earlier, and those north of the river to the later, period.

(3) The high terraces on the Big Sandy, in Teazes Valley, at the junction of the Kanawha and Elk Rivers, and near Morgantown, Fairmont, and Clarksburgh, in West Virginia, and at Carmichaels on the Monongahela, in Pennsylvania, can with difficulty be assigned to that remote period when the streams in those valleys flowed over rocky beds at heights corresponding to the height of the terraces. Slack water of some kind must be supposed to account for their evidently recent origin.

(4) The fine character of the sediment constituting the overwash in front of the moraine at the head of Baker's Fork of Brush Creek, in Pike County, Ohio, indicates a body of still water there at a height corresponding to that of the supposed Cincinnati dam. The absence of terraces, and indeed of any northern drift along the lower portions of Brush Creek, is additional proof of the same condition of things.

(5) Many of the high level terraces in the upper Ohio and its tributaries may be but remnants of river beds when the rocky bottom was at that level. But, since some of them were as evidently due to slack water deposition, when floating ice was abundant, simply considering them in themselves, it would remain to choose between two theories as to the cause of the slack water. The ice-dam theory has a rival in that of the general submergence of the Alleghany plateau to a depth of a thou-

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sand feet or more. This has against it the enormous amount of change implied. It is an inordinate cause to introduce to account for so small a result. Furthermore, according to Prof. Lesley, there are not any corresponding terrace remnants on the east side of the Alleghanies, as there should be on this theory. Still, this is a point to be more fully investigated. The deposits of gravel and pebbles in the valley of the upper Potomac above Cumberland without much doubt mark former levels of the river bed and do not imply a submergence. I have not seen any definite descriptions of deposits farther south corresponding to these still-water deposits which I have attributed to the obstruction by the Cincinnati ice dam.

As the case now stands in my own mind, both the theory of continental depression and that of such an enormous period between two nearly conterminous fields of successive glaciation as is implied in attributing the deposits south of the Ohio and the high level terraces of the upper Ohio to a glacial period when the rivers flowed in rocky beds of corresponding height, must give place to the simpler theory that the ice, which all admit extended at no very distant date to the north bank of the Ohio for a distance of 50 miles, also extended at that time a few miles farther, and temporarily obstructed the channel, forming thus an ice dam of about five hundred and fifty or six hundred feet in height.

On this supposition, so natural in itself, all the facts are easily explainable. So confident have I become in the reality of this dam that I have not hesitated to use it as a means of putting myself in the line of discovering other facts which are the natural consequence of this. Many of the facts enumerated in this paper (as, for example, those connected with the headwaters of Brush Creek) were thus discovered. It was reasoned that they must exist from the nature of the supposition; and upon examination in proper localities it was found that they did exist according to previous calculation. I need not say that such experience is the most convincing proof of a theory.

## THE LOESS AND ITS RELATION TO THE GLACIAL DRIFT.

A striking characteristic of the glacial deposits in southern Illinois, Indiana, and Ohio is that they are overlaid, to a greater or less extent, by a very fine deposit almost devoid of grit and wholly free from gravel. Near the Missouri and Mississippi Rivers this is of great extent, sometimes being as deep as 100 feet, and being of such texture that wells dug in it to that distance will stand for years without curbing. There seems to be no signs of stratification in this deposit, and its origin is a question hotly disputed, some writers, like Richtofen, Clarence King, and Pumpelly maintaining that it is the accumulation of dust which in the course of ages has been brought along by the wind.

But the more general opinion is that it is a water deposit, though upon that theory the absence of stratification and of the remains of shell-fish is difficult to explain. In southwestern Iowa Prof. J. E. Todd took

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me to a fresh section fifteen or twenty miles back from the Missouri River and several hundred feet above it, where a blanket of loess about twenty feet in thickness rested unconformably on irregular deposits of till, while near the junction of the loess and the till a stratum, a foot or more in thickness, contained many fragments of carbonized or half-decayed wood.

In my recent investigations I have kept in mind these problems concerning loess, but I can not say that very much light is shed upon them by my observations. Their whole relation to the glacial deposits throughout the region I have more particularly investigated is to me very perplexing.

In the first place, there seems to be no material difference between the loess covering the hills in Perry County, Missouri, entirely outside the glaciated region, and that superimposed upon the glacial deposits of Randolph and Jackson Counties, upon the opposite side of the river, in Illinois. The deposits upon the high lands of Perry County would be ordinarily and reasonably reckoned residuary clays, resulting from the decomposition of the limestone rocks upon which the deposit rests. Yet a chemical analysis fails to reveal any essential difference between the deposit in that place and that which rests upon the surface everywhere in southern Illinois. A partial analysis of two specimens taken from a cut near Perryville, Perry County, Missouri, 10 miles back from the river, and about three hundred feet above it, where the loess is about ten feet deep, gives the following results:

| First specimen, 2 feet below the surface: | Per cent. |
|---|---|
| $CO_2$ | .061 |
| CaO | .164 |
| MgO | .264 |
| Second specimen, 5 feet below the surface: | |
| $CO_2$ | .057 |
| CaO | .237 |
| MgO | .201 |

The next three specimens are taken from a cut in Randolph County, Illinois, several miles east of Chester. The cut is about twenty-five feet deep, and for the first 10 feet is without much grit and perfectly free from gravel; but gradually it merges into a deposit having every characteristic of true till. Three specimens of soil were taken from this cut, of which the first was near the surface, the second 10 feet lower, and the third 23 feet lower still. The following are the determinations of the same elements sought for in the preceding specimens from Missouri:[1]

| First specimen, near the surface: | Per cent. |
|---|---|
| $CO_2$ | .184 |
| CaO | .257 |
| MgO | .203 |

[1] These determinations were made by Mr. W. C. Metcalf, who accompanied me in this portion of the field.

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Second specimen, 10 feet below the surface:

| | |
|---|---|
| $CO_2$ | .101 |
| CaO | .207 |
| MgO | .128 |

Third specimen, 23 feet below the surface:

| | |
|---|---|
| $CO_2$ | .149 |
| CaO | .347 |
| MgO | .192 |

The uniformity of composition in these specimens is certainly remarkable, as is the small amount of carbonic dioxide in each, being in no case as much as one-quarter of 1 per cent. In several specimens, however, from other places in southern Illinois a marked increase in carbonic dioxide was found in the lower portions of the deposits. For example, near Phillipstown, White County, a specimen from the fine soil near the surface shows but 0.039 per cent, while that from the till underneath gives 5.792 per cent of $CO_2$. In another cut in the same town the specimen from three feet below the surface yields no $CO_2$, while that from 10 feet yielded 7.029 per cent. Again in Heralds Prairie township, in the same county, a specimen from three feet below the surface, which is entirely free from gravel, yields 0.018 per cent of $CO_2$, while one four feet lower in what is noted as true till yields 6.007 per cent of $CO_2$. Again, in a cut three miles south of New Harmony, Posey County, Indiana, near the extreme limit of glaciation, the upper specimen, from two feet below the surface, yields 0.229 per cent, while that from 10 feet lower yields 6.032 per cent of $CO_2$.

The absence of any sharp line of demarkation between the loess and the till has also been both unexpected and puzzling. In oft-repeated instances the upper portion of a cut revealed several feet of loess entirely free from gravel, while, a few feet below, the till was unmistakable in its character and for two or three feet between, the character of the material was intermediate between that of loess and till. This occurred so often in both southern Illinois and Indiana that it may be set down as the prevailing characteristic. Over the southeastern part of Indiana there is a marked diminution in the amount of this superficial covering of loess. Still, it is nearly everywhere present. Over these counties there are extensive portions of the country occupying the summit of land, which is so level that drainage is extremely difficult. A few feet at the bottom appears to be compact till with granitic pebbles and scratched stones, while the surface and a few feet below is a light-colored loess.

Going still farther east, to Ohio, the phenomena are quite similar to those in the southeastern counties of Indiana (see above, p. 65 et seq.).

In Jackson County, Indiana, and farther west, near the sandstone knobs, the superficial deposit corresponding to the loess is a very fine sand, peculiarly favorable for the growing of melons. This would seem, evidently enough, to be a wind deposit. There is nothing corresponding to the loess in northern Ohio, so far as I know.

Considering the loess merely by itself, so far as it has come under my

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observation, it would seem to be largely a residuary clay, and would most readily be accounted for by supposing a depression in the Mississippi Valley of several hundred feet after the continental glacier had attained its extreme limit, and then retreated to about the line marked by President Chamberlin as the limit of the ice during the second glacial epoch. Such an interglacial sea would have had poured into it the finer material washed down from the more northern regions, which would settle unconformably upon the older glacial deposits below. But the complete application of this theory of depression would involve so great changes in the more western and northern portions of the Mississippi Valley that it is doubtful to my mind whether it is tenable. Many of the phenomena of the loess may be accounted for, perhaps, by mere local causes. Temporary lakes may have been formed by slight orographic changes in different places. Over some of the extensive prairies of southern Illinois the direct wash from the melting ice to the north may have spread a film of fine material over the whole region to the south. Again, the winds may have had a considerable share in transporting this fine material before vegetation had advanced to cover the region from which the ice had recently retreated.

Professor Orton, anticipating Darwin's book on worms, many years ago suggested, in reference to the deposits in Highland, Brown, and Clermont Counties, Ohio, that the fine material had been brought to the surface through the agency of worms and other burrowing animals. President Chamberlin had also suggested this explanation for portions of the field. Such an explanation would seem the more reasonable over the regions mentioned in Ohio and southeastern Indiana, because of the comparative thinness of the deposit. The indefiniteness of the line of demarkation between the loess and the till over so wide a portion of the region would also favor the same view, except that frequently the depth of the loess is so great as to render such agencies insufficient. Still, perhaps the wind may in many instances have increased the depth.

## GOLD NEAR THE GLACIAL MARGIN.

A few words should be said respecting the frequent discovery of gold near the glacial margin, since it is so often the cause of serious delusion. The whole region covered by my special investigations and lying west of the Blue Ridge in Pennsylvania, is covered with stratified deposits of the Upper Silurian, Devonian, and Carboniferous ages. So little disturbed are they that it would be hopeless to look for gold in them. The natural explanation, then, of finding gold anywhere in this region would be that it was a part of the glacial transportation from the granitic region to the north. I soon learned from experience that the gold diggings were sure to be located near the glacial margin, where it might be supposed that the till had been most weathered and washed, and which had, presumably, been skimmed from the disintegrated surface of the northern rocks on the first advance of the glacier over them. In this border

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gold has been found frequently in quantities to repay a moderate expenditure in washing the gravel, but never in large quantities. I found such deposits in Brown County, Indiana (and indeed in all the southeastern counties of Indiana), in Brown, Clermont, Licking, and Knox Counties, Ohio, and in Lycoming County, Pennsylvania. In all cases these deposits are within the glacial boundary, and are near the glaciated margin.

The irregular and serrate character of the southern boundary of the glaciated region, along which these gold deposits are found, led Dr. Sutton[1] to speculate from false data as to the particular source of the gold. The relations of the gold deposits in Dearborn, Jennings, and Scott Counties, Indiana, to those in the northern part of Brown County, in the same State, are wholly accidental, arising from the irregularities in the glacial boundary. But, before that fact was discovered, it was natural to think them significant. Consequently an attempt was made by Dr. Sutton to locate the original gold accumulations to the far north by projecting the lines which were determined by the points in the southeastern counties and those in Brown County. I was more successful soon afterwards, when I had come to see the significance of the gold, in inferring from the reports of diggings what was the vicinity of the glacial margin in the localities named.

## INTERGLACIAL MAN IN OHIO.

At the meeting of the Boston Society of Natural History for November 4, 1885, Prof. F. W. Putnam showed an implement chipped from a pebble of black flint, found by Dr. C. L. Metz in gravel 8 feet below the surface, in Madisonville, Ohio. This rude implement is about the same size and shape of one, made of the same material, found by Dr. C. C. Abbott in the Trenton, New Jersey, gravel, and is of special interest as the first one known to have been found in the glacial gravels of Ohio. The announcement of this discovery, coupled with a letter from Dr. Metz, saying that he had since found another such implement at Loveland, led me to visit the localities to see their relation to the glacial deposits of the region. The following are the results:

Madisonville is situated 11 miles northeast of Cincinnati, in the depression of a preglacial valley connecting the Little Miami River with Mill Creek, about 5 miles back from the Ohio. The Little Miami joins the Ohio some miles above Cincinnati, while Mill Creek joins it just below the city. The general height of the hills in that vicinity above the river is from 400 to 500 feet. But the hills just north of Cincinnati are separated from the general elevation further back by the depression referred to, in which Madisonville is situated.

The depression is from one to two miles wide and about five miles long from one stream to the other, and is occupied by a deposit of gravel,

[1] See abstract of paper on the gold-bearing drift of Indiana, Proc. Am. Assoc. Adv. Sci., 30th (Cincinnati) meeting, 1881, p. 177.

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sand, and loam, clearly enough belonging to the glacial-terrace epoch. The surface of this is generally level, and is about two hundred feet above the low-water mark in the Ohio. On the east side, towards the Little Miami River, at Red Bank, the gravel is rather coarse, containing pebbles, ranging from one to three or four inches, interstratified with sand, and underlaid near the river level with fine clay. There is here a thin covering of loess, or fine loam. On going westward this loess deposit increases in thickness, being at Madisonville, one mile west, about eight feet thick. Further west it is much deeper, and seems to take the place of the gravel entirely. At several railroad cuttings, "till," with scratched stones, appears underneath all.

Thus it appears that this cross-valley connecting Mill Creek with the Little Miami back of Avondale, Walnut Hills, and the Observatory was once much deeper than now, and has been filled with the deposits made when immense glacial floods were pouring down these two streams from the north. The Little Miami was a very important line of glacial drainage, as is shown by the extensive gravel terraces all

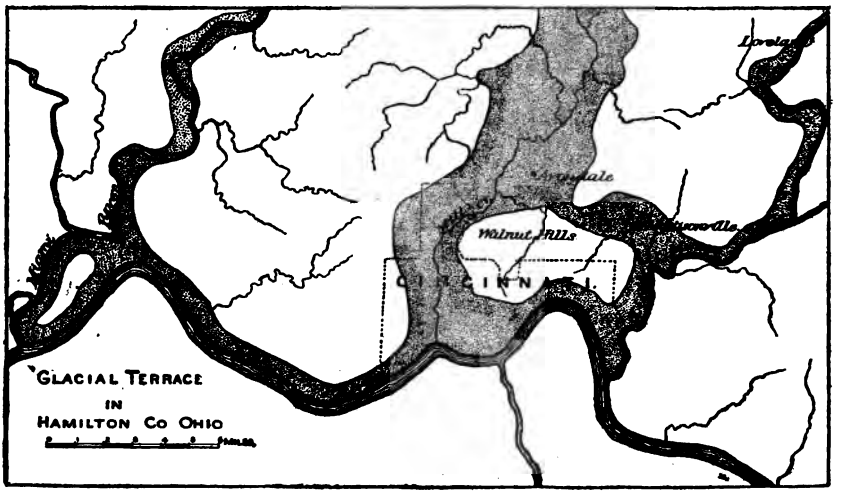


FIG. 10.—Map of Hamilton County, Ohio, showing situation of glacial terrace in which paleolith was formed.

along its course. The railroads resort to these terraces for ballast from long distances. The coarser material was naturally deposited near the direct line of drainage, where the current was strong. Naturally also back from the river towards Madisonville there is an increase of the fine deposit, or loess, which is particularly a still-water formation. There can thus be no doubt as to the true glacial character of the formation.

As to the implement, it is preserved in the Archæological Museum in Cambridge, Massachusetts, where any one can examine it and compare it with similar ones from other parts of the world, and is of the true paleolithic type. It is not smoothed, but simply a rudely chipped,

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pointed weapon, about three inches long. Dr. Metz found it in 1885, while digging a cistern. In making the excavation for this he penetrated the loess eight feet before reaching the gravel, and there, near the surface of the gravel, this implement was found. There was no chance for it to have been covered by a slide, for the plain is extensive and level topped, and there had evidently been no previous disturbance of the gravel.

Subsequently, in the spring of 1887, Dr. Metz found another paleolith in an excavation in a similar deposit near Loveland, Ohio. Loveland is also on the Little Miami River, about twenty miles above Madisonville. The river makes something of an elbow at this point, opening to the west. This space is occupied by a gravel terrace about fifty feet above the stream. The terrace is composed in places of very coarse material, resembling very much that of Trenton, New Jersey, where Dr. Abbott has found similar implements. The excavation is about one-quarter of a mile west of the river, near the residence of Judge Johnson. The section shows much coarser material near the surface than at the bottom. The material is largely of the limestones of the region, with perhaps ten per cent. of granitic pebbles. The limestone pebbles are partially rounded, but are largely oblong, some of them being from one to three feet in length. These abound for the upper 20 feet of the section on the east side towards the river. One granitic bowlder was about two feet in diameter. On the west side of the cut, away from the river, mastodon bones were found, not long before, in a deposit of sand underlying the coarser gravel and pebbles. It was here, about thirty feet below the surface, that Dr. Metz found the paleolithic implement in question, which is an oblong stone about six inches long, four and one-half inches wide, chipped all around to an edge, and is, in the opinion of Dr. Metz and of Prof. H. W. Haynes, of Boston (a most competent judge), unquestionably of human manufacture. This, like the preceding implement, can be seen in company with Dr. Abbott's collection from Trenton, New Jersey, at Cambridge, Massachusetts.

Another similar discovery was made in 1886 at Medora, Jackson County, Indiana, by Mr. Hilborne T. Cresson, an experienced archæologist, of Philadelphia. Medora is upon the east fork of White River, near where it emerges from the glaciated region to enter the triangular unglaciated portion of southern Indiana, as shown upon our map. According to Mr. Cresson, a well-wrought paleolithic flint implement was found by him at this point in undisturbed gravel 11 feet below the surface, and about fifty feet above the flood-plain of the river, and in position such as to exclude its introduction, except in connection with the original deposit of the material. This implement is also in the Peabody Museum, Cambridge, Massachusetts.[1]

A fourth discovery was made on the 27th of October, 1889, by Mr. W. C. Mills, at New Comerstown, Tuscarawas County, Ohio. This is a

[1] See proceedings of the Boston Society of Natural History, vol. 24, p. 150 et seq.

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fine specimen of the true paleolithic type four inches long, two inches wide, and an inch and a half in thickness, tapering to a point, and in every respect of true paleolithic type, such as has characterized the discoveries in northern France and southern England. The material is a black flint, such as occurs in nodules in the "Lower Mercer Limestone" of the near vicinity. The implement has the waxy, glossy appearance which indicates considerable age, and was found by Mr. Mills in a gravel-pit from which the railroad has, for a long time, been at work obtaining ballast. Upon receiving information of this discovery, I visited the locality, and found, as I had surmised from Mr. Mill's description, that the gravel-pit at New Comerstown belongs to the glacial terrace of the Tuscarawas River Valley which I have described in the body of my report. The trough of the river is here about a mile in width, and the summit of this terrace 35 feet above the flood-plain. Mr. Mills found the implement in undisturbed strata of this terrace, 15 feet below its surface.

By those familiar with the subject these paleoliths will at once be recognized as among the most important archæological discoveries yet made in America, ranking on a par with those of Dr. Abbott, of Trenton, New Jersey. They show that in the Mississippi Valley, as well as on the Atlantic coast, man was an inhabitant before the close of the glacial period.

## GENERAL CONCLUSIONS.

On surveying the whole field of my investigations and limiting my conclusions mainly to what the facts there found would make necessary, the following would seem to have been the course of events:

From some center north of the great lakes snows accumulated until an ice flow to the south became necessary to dispose of the excess of the snow-fall over the annual melting power of the sun. This snow-fall was greater at some points than at others, so that there were separate subcenters for the outflow of the glacial ice. Thus, in part, is to be explained the serrate character of the southern margin of the glaciated region, the ice projecting farthest opposite the larger accumulation of snow. The lower level of the larger valleys had also some effect upon the distance of the southern flow. There would seem to be no conclusive evidence that isothermal lines had anyhing to do in determining the irregularity of the southern margin. But they may have had some influence.

The ice as it moved onwards pushed on before it and incorporated into it much material that had been disintegrated by previous subaerial agencies, and also executed a large amount of mechanical erosion by its own force. This is evident both from the extensive fields still retaining the glacial grooves and scratches, and by the demonstrated mechanical character of much of the till. It is probable that the deposits near the margin are, more largely than those farther back, the product of preglacial disintegration. This would account for their

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generally being more completely oxidized, and their consequent higher color. The rate of the advance of the glacier probably can not be directly determined by any facts accessible in this field.

Having advanced to its extreme southern limit, and the climate becoming ameliorated, the ice began slowly and irregularly to recede, occasionally readvancing to cover again ground from which it had temporarily withdrawn. In some instances, as where the buried forests are found, some scores or hundreds of years may have intervened between the retrocession and the advance over limited areas.

The formation of a terminal moraine at any point would depend upon two or three factors: First, upon how long the ice front remained stationary at a given point. Other things being equal, the longer the ice front remained at a point the greater would be the accumulation there. For some reason, the ice front would seem to have been longer stationary along the southern coast of New England than at marginal points farther west, perhaps because the waters of the ocean there met it and prevented it from attaining its natural southern limit. In the interior it would seem that the ice retreated rather steadily over most of the space occupied, so that the material which otherwise would have been heaped up in front as a terminal moraine is more uniformly spread over a wide margin, making up in breadth what it lacks in height.

During the time that the ice extended into Kentucky an ice dam was probably formed about 550 feet in height (that being the height of the barrier to the south), sufficient to set the water 300 feet over Pittsburgh. This long, crooked, narrow, slack-water lake is supposed to have continued long enough for considerable material to accumulate at various points above, where tributary streams, laden with sediment, joined the main body of water. The length of the continuance of this condition of things need not have been many hundred years.

The overlying loess in southern Illinois and Indiana, and the analogous formations over some of the counties of Ohio perhaps make it necessary to suppose a depression of that region soon after the beginning of the retreat of the ice from its extreme southern limit. This depression may also have extended to the Alleghanies, and so have had something to do in producing some of the effects attributed to the ice obstruction at Cincinnati.

In the more northern region, near the lakes, there are regions of stratified sand and gravel superimposed upon the till to a height of about 200 feet above Lake Erie, and at several lower levels towards the lake. These are evidently water deposits, and most likely bars formed a little outside the shore when the water stood at that height. The material of these ridges is largely local. From the extent of these ridges and the character of the surrounding country it would seem that the water did not remain long at the several levels indicated by these deposits. There are no animal remains in the lake ridges, but wood is often found underneath, and especially to the south of them on the side away from

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the lake. The theory has been suggested, and seems altogether probable, that the barrier holding this body of water at such a high level was the unmelted ice of the glacier, which naturally remained longest to the north and east, across the valleys of the Mohawk and St. Lawrence.

Upon the question of the time which has elapsed since the withdrawal of the ice it is as yet too early to express any confident opinion. So far as the facts go, however, they point to a moderate estimate. The freshness of the wood that is found beneath the deposits of till, the small amount of erosion, both in the river valleys and in the gorges below the numerous waterfalls, together with the small extent to which the till has in general been oxidized, all would indicate a brief period of post-glacial time when compared with the enormous lapse of time during which the Ohio was wearing its long trough from a little above the Mississippi to the headwaters of the Alleghany and the Monongahela.

Through all this distance of not less than 1,200 miles the stream has worn a channel about a mile in width and several hundred feet in depth. The prosecution of investigations concerning post-glacial chronology will be of great historic interest if, as would appear from the discoveries of Dr. Abbott at Trenton, N. J., and those of Dr. Metz at Madisonville and Loveland, Ohio, Mr. Cresson at Mentone, Ind., and Mr. Mills at New Comerstown, Ohio, man was on the continent before the glacial ice had withdrawn from the headwaters of the Delaware and Little Miami rivers. The facts brought to light in the present report will greatly aid in such calculations. The subject merits more careful study than has heretofore been devoted to it.

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DEPARTMENT OF THE INTERIOR

# BULLETIN

OF THE

# UNITED STATES

# GEOLOGICAL SURVEY

## No. 60

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UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

# REPORT OF WORK DONE

IN THE

# DIVISION OF CHEMISTRY AND PHYSICS

MAINLY DURING THE

# FISCAL YEAR 1887-'88

F. W. CLARKE, Chief Chemist

WASHINGTON
GOVERNMENT PRINTING OFFICE
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# PREFACE.

The present bulletin, like its predecessors numbered 9, 27, 42, and 55, contains the results of work completed in the Division of Chemistry and Physics during one fiscal year. Part of the investigations reported were begun in previous years; and other researches which are now under way are reserved for future publication. Still other work has appeared, or will appear, in separate bulletins; so that this issue represents only a part of the results obtained during the year which it covers.

F. W. CLARKE,
*Chief Chemist.*

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# WORK DONE IN THE DIVISION OF CHEMISTRY AND PHYSICS IN 1887-'88.

## THE CHEMICAL STRUCTURE OF THE NATURAL SILICATES.

By F. W. Clarke.

In any attempt to discuss the chemical structure of the inorganic silicates we are met at the outset by difficulties which are partly real and partly imaginary. On the one hand we have to deal entirely with non-volatile solids, of which, because of their fixedness, we can not certainly ascertain the true molecular weights. They are, furthermore, insoluble and, chemically speaking, non-plastic; that is, they yield but stubbornly to reagents, so that the changes of which they are structurally capable can rarely be studied in the laboratory. These difficulties are very real. On the other hand, most of the definite silicates are natural minerals, and as such are commonly supposed to have a bewildering complexity of constitution. This difficulty is only apparent, not real, and is due to several causes. First, few mineral species occur in a state of even approximate chemical purity; and secondly, many of them, being isomorphous, crystallize together to form seemingly homogeneous bodies to which rational formulæ can hardly be assigned. Impurities, indefinite crystalline mixtures, and defective analyses account for many apparent complications. Eliminate from any group of natural silicates these disturbing conditions, and we shall find in every case a simplicity of composition far removed from the complexity which is popularly assumed. Even on theoretical grounds we should expect simplicity of structure. The mineral silicates are, as a rule, exceedingly stable compounds, while complex molecules are relatively unstable. They are formed in nature under conditions of high temperature, or are deposited from solutions in which many reactions are simultaneously possible; circumstances that are strongly adverse to any great complications of structure. Finally, they are quite limited in number, only a few hundred at most being known; whereas, if complexity were the rule among them, slight variations in origin would produce great variations in character and millions of different minerals



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would be generated. That few substitutions occur is presumptive evidence that only few are possible, and hence simplicity of constitution is to be inferred. In fact, we find the same small range of mineral species occurring under the same associations in thousands of widely separated localities, a few typical forms containing a few of the commonest metals being almost universally distributed. The longer the evidence is considered the more overwhelming the argument for simple silicate structures becomes.

Suppose now that for any given silicate the empirical composition has been ascertained, how can its chemical structure be determined? We can not measure its vapor density and so deduce its molecular weight; but the problem is not therefore necessarily hopeless. Several lines of available evidence are open. In some cases the compound may be synthetically reproduced in the laboratory, a kind of mineralogical investigation in which rapid progress is now being made. Again, the constant association of the species with certain others sheds light upon its genesis, and still oftener its alterations in nature furnish important details. An alteration product, despised by the crystallographer, is really a record of chemical change, and such products may be of the highest scientific interest. In a few researches they have been produced artificially by reactions which were prolonged for months at a time, and so a mass of evidence is slowly accumulating, strictly analogous in kind to that which the organic chemist chiefly depends upon for ascertaining the structure of a hydrocarbon. All these lines of evidence are legitimate, and all converge towards truly scientific conclusions. We know that certain silicates originated together, and that each alters in certain definite ways; and from these facts we may draw perfectly fair inferences as to chemical structure and deduce rational formulæ which shall give fuller expression to our knowledge. The evidence for such formulæ is less perfect than that at the command of the carbon chemist, but it is none the less substantial so far as it goes. It is, furthermore, cumulative.

About three years ago, while I was working tentatively at the problem now under discussion, I received for examination certain specimens of topaz which were deeply altered upon their surfaces. Upon investigation the alteration product proved to be a variety of muscovite, and a study of the empirical formulæ of the two minerals revealed an unexpected relation between them. Further study brought out more extended relations connecting them with several other silicates, and by a natural series of steps I was led to adopt as a working hypothesis the supposition that double salts might be regarded as substitution derivatives of normal salts. This hypothesis, since then steadily applied to the discussion of the silicates, appears to be supported by a weighty mass of evidence, and it leads to the development of a series of structural formulæ which satisfy many conditions. They express and interpret known relations, lead to the detection of others, and point out suggestive and profitable

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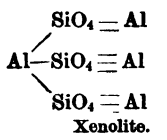
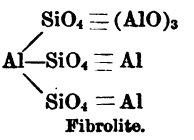
lines of research. By these tests any hypothesis must stand or fall, and one which, meeting them successfully, has at the same time philosophical significance, may be fairly looked upon as valid.

That the great majority of the natural silicates are double salts need hardly be stated, and that a very great number of them contain aluminum is also a commonplace of chemistry. Of the latter some are orthosilicates, and some are meta-compounds; and the problem is to show how each series may be derived from its corresponding normal salt. As the orthosilicates are the most important, we may begin with their consideration. They represent the maximum of complication and offer the greatest difficulties.

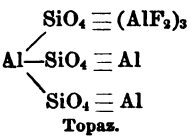
Fortunately, the orthosilicate of aluminum $Al_4(SiO_4)_3$, occurs in nature as the mineral xenolite. This species, which is now well established, was long thought to be an impure variety of fibrolite, $Al_2SiO_5$; and in their optical properties the two are apparently identical. Fibrolite bears the closest of relations to its isomer, andalusite; and to the latter, topaz, $Al_2SiO_4F_2$, is crystallographically akin. Topaz, as I have already stated, alters into muscovite, $Al_3KH_2(SiO_4)_3$; and so also does eucryptite, $AlLiSiO_4$. To these compounds we may add paragonite, which is merely a sodium mica, and we have at least six silicates, including the normal salt, which are all evidently related to each other. That their empirical formulæ show little or no connection is due to the fact that they do not represent true molecular weights, and on this point our fundamental hypothesis gives us a key to the problem. If we triple the formulæ given for fibrolite, topaz, and eucryptite, the substitution theory which I have suggested at once becomes applicable, and the derivation of all the others from xenolite is easy. The following structures will make this conception clear:



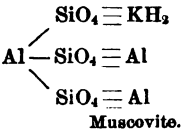
Xenolite.



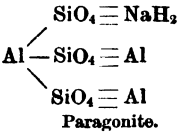
Fibrolite.



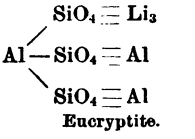
Topaz.



Muscovite.



Paragonite.



Eucryptite.

In the second of these formulæ the univalent group $-Al=O$ is assumed, and in the third we have the corresponding group $-Al=F_2$. I think no chemist will regard these assumptions as strained.

Now the foregoing symbols all represent a series of salts derived from the first one by various substitutions of a single aluminum atom.

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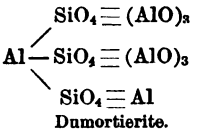
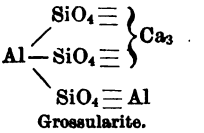
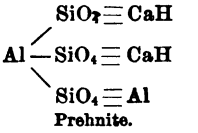
But further replacements are theoretically possible, and the following minerals seem to illustrate them:



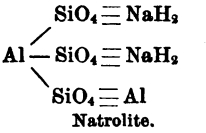
Dumortierite.



Grossularite.



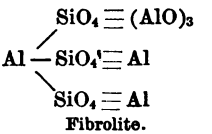
Prehnite.



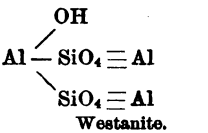
Natrolite.

Dumortierite, which has been little studied, appears to be related to fibrolite, and the formulæ exhibit a relation. Grossularite, the lime alumina garnet, is a common associate of muscovite, a fact which lends verisimilitude to the formulæ given above. The other two formulæ represent the known composition of prehnite and natrolite, but whether they indicate any deeper relations is not yet proven. They do, however, suggest lines of investigation, and so far fulfill a useful purpose. If they are true, prehnite should be derivable from garnet, and garnet and muscovite ought to be mutually derivable from each other. That garnets do alter into micas is already well known, although the exact character of the change is undetermined, and the micas involved in the reaction appear to be more complex than muscovite.

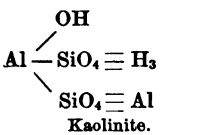
Returning now to fibrolite, we find that it is a mineral which is liable to alter through a process of hydration. Some of its alteration products have been described as species, notably under the names wörthite and westanite, the latter being apparently the final product. Certain other species of the same group frequently undergo a sort of degradation into clays, which, unfortunately, are often too impure to admit of precise formulation. Still, of the several clays which are certainly definite, two seem to fall into series with fibrolite and westanite, as the following structures show:



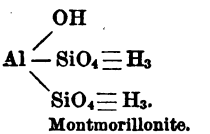
Fibrolite.



Westanite.



Kaolinite.



Montmorillonite.

Now, suggestive as these formulæ are, they represent only a selection out of a much larger number, all of which seem to follow essentially

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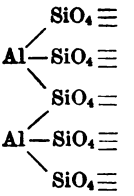
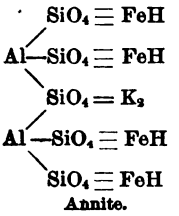
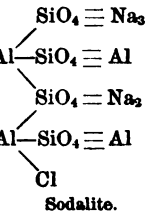
the same structural rule. If the case rested here it would still be a strong one, but it becomes even stronger when we study some of the more complex orthosilicates, and some of the silicates containing other inorganic acids. In most of the foregoing instances we have one aluminum atom linked with three of the orthosilicic groups, making a sort of fundamental nucleus to which the other atoms of each molecule are attached. But in many cases we seem to have a semipolymerisation of that nucleus which results in the elimination of one of the silicas, leaving a new group of atoms which may be represented as follows:



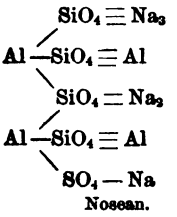
This group, saturated by various bases, seems to exist in many natural silicates, notably among the iron and magnesian micas; and from it certain mixed salts, like sodalite and nosean, may be represented as derived. Thus, to cite a few examples, we may write:



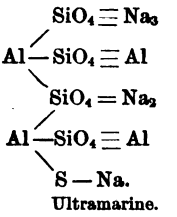
Annite.



Sodalite.



Nosean.



Ultramarine.

The last of these four formulæ is purely hypothetical and rests upon the recognized mineralogical analogies between lapis lazuli and nosean. It is, however, a formula which should be capable of synthetic verification, for ultramarine, itself a product of synthesis, yields many derivatives, the formation of which can be systematically studied. Possibly the lines of research followed by Lemberg, in his work on the alterations of elacolite, may be fitly applied to the investigation of lapis lazuli. As for annite, I have discussed its relations, together with those of the lithia micas, in a previous paper,[1] in which I have also given some

[1] Amer. Journ. Sci., Nov., 1886.



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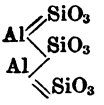
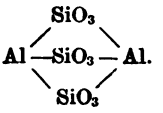
suggestions concerning the part played by fluorine in lepidolite, cryophyllite, and phlogopite. Sodalite and nosean were considered in a still earlier paper,[1] in connection with cancrinite, nephelite, and other species. It is hardly necessary to repeat either discussion here.

Passing now to the metasilicates, we find ourselves, as regards the aluminous salts, at some disadvantage. The normal compound, $Al_2(SiO_3)_3$, is not known to exist by itself in nature, although certain of its derivatives are common. Its formula, however, may be written in two ways, as follows, and to one of these types some of the double aluminous metasilicates should conform:

I.

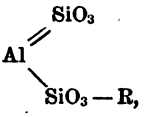



II.

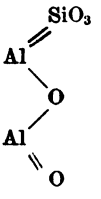



Which of the two is best sustained by evidence?

To answer this question we may appeal to several well-known minerals, such as spodumene $AlLi(SiO_3)_2$, jadeite, $AlNa(SiO_3)_2$, leucite, $AlK(SiO_3)_2$, and pyrophyllite, $AlH(SiO_3)_2$. All of these can be generalized under one formula, thus:




which is directly derivable from normal salt No. 1, and is not derivable from No. 2. Furthermore, kyanite, an isomer of fibrolite, $Al_2SiO_5$, is regarded by Groth and others as a basic metasilicate, for reasons which need not be reconsidered here. As such its formula is $Al_2(SiO_3)O_2$, which may be derived from either of the formulæ for the normal compound. But pyrophyllite often occurs as the gangue of kyanite, which suggests a genetic relation between the two, and so makes it highly probable that the latter mineral should be written




rather than as a derivative of the second formula for $Al_2(SiO_3)_3$. Formula No. 1, then, is the more probable formula for aluminum metasilicate. Two isomers may be possible, but the evidence so far favors only one compound.

[1] Amer. Journ. Sci., April, 1886.

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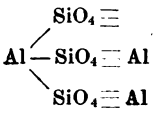
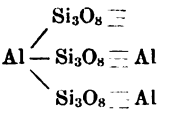
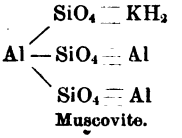
In addition to orthosilicic and metasilicic acids, at least two other silicic acids correspond to known salts. These are the compounds $H_2Si_2O_5$ and $H_4Si_3O_8$. Still more are possible, but it is not necessary to assume them in order to account for known minerals. Derived from $H_2Si_2O_5$ we have a few species, notably petalite, $AlLi(Si_2O_5)_2$, which is the equivalent of spodumene in structure. The other acid, $H_4Si_3O_8$, is represented only by the species albite and orthoclase, $AlNaSi_3O_8$ and $AlKSi_3O_8$ respectively. If we triple these formulæ we have structures quite analogous to the orthosilicates, in which the normal aluminum salt $Al_4(Si_3O_8)_3$ is the starting point for derivation. Now it is almost universally believed, in accordance with the views of Sterry Hunt and Tschermak, that the triclinic feldspars consist of various mixtures between albite and anorthite as two extremes. If our fundamental hypothesis is true, each of these minerals is derived by substitution from a normal salt, and the formulæ so deduced become strikingly suggestive:

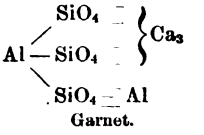


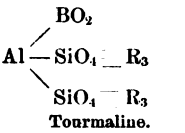

Anorthite is the lime salt corresponding to the first formula, and albite is the soda salt corresponding to the second. Another comparison is even more striking. The four silicates most frequently associated with each other in granite veins are muscovite, garnet, albite or orthoclase, and tourmaline. Tourmaline, according to the analyses made by Mr. Riggs in the laboratory of the United States Geological Survey, is always represented by the general formula $R'_9BO_2(SiO_4)_2$, in which at least the equivalent of $R'_3$ is present as aluminum. This gives us the following quartette of formulæ:



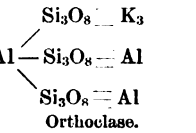

Muscovite.




Garnet.




Tourmaline.




Orthoclase.

The suggestiveness of these symbols can hardly be questioned. All four are covered by the one general hypothesis; and tourmaline, furthermore, is known to alter into muscovite.

Leaving the aluminous salts, the other silicates present few structural difficulties. Isomorphous mixtures become perhaps more common, but when they are resolved into their constituents relatively simple compounds are found. The commoner bivalent metals form both ortho- and

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metasilicates, and to them the substitution hypothesis, as a rule, easily applies. Only in the metasilicate series do we find notable difficulties, and they may be avoided by the assumption of polymeric molecules. Thus, instead of $R''SiO_3$ we should write $R''_2(SiO_3)_2$, in which one atom of R'' becomes replaceable. This conception is by no means new, and is indeed quite commonly in use; but I may be permitted to cite one item of evidence in its favor. When solutions of calcium chloride and sodium metasilicate are mixed, a white precipitate of calcium metasilicate is thrown down. This reaction I have studied under various conditions of temperature and concentration, and I find that when the precipitated salt is carefully dried over sulphuric acid it has the composition $2CaSiO_3.5H_2O$. That is, the double molecule $Ca_2Si_2O_6$ is required in order to avoid a formula containing a half molecule of water. By itself this fact is not of weighty importance, but it counts for something in confirmation of the prevalent views.

Concerning mixed silicate molecules, partly ortho- and partly meta-compounds, I have nothing at present to say. Such silicates undoubtedly exist, as well as aluminous silicates derived from normal salts of magnesia or lime. Nor do I venture to assert that all known silicates are as yet interpretable by simple structural means. There are many outstanding cases which still seem very obscure, but which I confidently expect will be cleared up in time. The micas, chlorites, and scapolites especially need a great deal of further study. Various theories have been proposed to account for the composition of these groups, but not one is absolutely conclusive and satisfactory. The new method of discussion which I have proposed is yet to be fully applied to these minerals but a wider knowledge of their variations is essential to its complete application. Whether the method shall be finally established as valid remains to be seen, but its results so far at least entitle it to respectful consideration. As a working hypothesis the substitution theory has value, even though it should be ultimately overthrown.

In conclusion, there is one question to be considered. With the silicates the supposition that double salts are substitution derivatives of normal salts appears to work exceedingly well. But how about double salts in general? With such compounds as the sulphates, chromates, tartrates, oxalates, etc., there seem to be few difficulties; but with the double haloids, acetates, formates, etc., the case is not so clear. Their explanation is troublesome, at least in accordance with current views concerning the valency of their acid radicles; but those views are not absolutely incapable of modification. There may be exceptions to the general hypothesis of derivation, but chemists are not likely to be satisfied with partial theories, and all double salts ought to come under one common law. Toward that ultimate purpose the present paper tends, even though the road which it opens may not reach the final goal.

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## SOME NICKEL ORES FROM OREGON.

By F. W. CLARKE.

In or about the year 1881 extensive deposits of nickel silicates were discovered in Douglas County, Oregon. In appearance the ores are identical with the so-called "garnierite" and "noumeaite" of New Caledonia, and many specimens bearing these names have found their way into collections of minerals. At present the deposits at Riddle, Oregon, are being worked by the Oregon Nickel Company, and, through the kindness of Mr. Will Q. Brown, an admirable series of the ores was recently sent to the United States Geological Survey for investigation. According to Mr. Brown all the deposits lie at or near the surface, in beds from 4 to 30 feet thick. Mining is carried on through open cuts or quarries, and no second bed has ever been found underlying the first.

The specimens at my disposal represent a wide range of appearances. They include samples of the country rock and of the associated chromite, and the nickel silicates themselves vary much in color and texture. The finest specimens are bright apple-green and quite compact, and from this they range through duller shades into masses of distinctly earthy texture. Most of them are intermixed with oxides of iron and with quartz; and even the purest mineral, like the garnierite of New Caledonia, is seamed with thin sheets of chalcedony. All of the nickel bearing samples are much decomposed; and one particularly beautiful specimen is distinctly a conglomerate or breccia, having nodules of the green ore imbedded in it side by side with pebbles and fragments of other material. Like all the nickel silicates which have been so far observed in nature, these ores are unmistakably products of alteration, and the problem of their genesis is somewhat interesting. For comparison with them I had a suite of the New Caledonia minerals, received from Professor Liversidge, and a large series of the genthites from Webster, N. C., collected by Mr. W. S. Yeates. All three localities have much in common, and the three sets of specimens point clearly to one conclusion, which will be stated farther on after the evidence for it has been presented.

In composition the nickel silicates from any locality vary widely; for the earthy nature of the material renders it impossible to secure anything like a homogeneous substance for analysis. The purest



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specimen of the Riddle ore was dark apple-green, compact, and amorphous; but so permeated with films of silica that a definite mineral could not be isolated. With the best material obtainable I secured the following results, which I give side by side with two published analyses by Hood,[1] in order to show the variations.

| | Clarke. | Hood. | Hood. |
|---|---|---|---|
| Loss at 110° C | 8.87 | 6.63 | 7.00 |
| Loss on ignition | 6.99 | | |
| $Al_2O_3 + Fe_2O_3$ | 1.18 | 1.38 | 1.33 |
| $SiO_2$ | 44.73 | 48.21 | 40.55 |
| MgO | 10.56 | 19.90 | 21.70 |
| NiO | 27.57 | 23.88 | 29.66 |
| | 99.90 | 100.00 | 100.24 |

Neither lime, sulphates, chromium nor cobalt could be detected. Like the New Caledonia garnierite, the fragments of this silicate fell to pieces when immersed in water.

Of the New Caledonia silicates many analyses have been published, notably by Liversidge and Leibius, Typke, Damour, Garnier, and Ulrich, and they vary between widely separated extremes. Not only are there the variations due to mutual replacements of nickel and magnesia, with a range in the percentage of NiO from 0.24 to 45.15 per cent, but there are also great differences in silica and in hydration. It is therefore impossible to say whether we have to deal with one nickel salt, varying only in its impurities, or with several compounds, although the general similarity of the material from different localities renders the former supposition the more probable. According to Ulrich[2] the noumeaite and garnierite consist of a soapstone-like base, with a hydroxide or silicate of nickel distributed through it in veins and patches; while Des Cloizeaux[3] regards noumeaite as a magnesian hydrosilicate impregnated with nickel oxide. The latter view, however, is hardly probable, especially when we consider the origin of the minerals; and Typke[4] has cited evidence against it. The prevalent opinion, that we have to deal with one or more definite hydrosilicates of nickel, is best sustained by careful comparative study of the specimens, even though the salts may not be obtained pure or positively formulated. The reciprocal variation of nickel and magnesia in more than twenty published analyses excludes from further consideration the idea that the nickel is present to any great extent as hydroxide. For temporary convenience we may use the well-recognized name "genthite" generically, and apply it to all the nickel silicates from the above-named localities.

[1] Mineral Resources of the United States, 1883.
[2] Amer. Journ. Sci., Third series, vol. 11, p. 235.
[3] Bull. Soc. Min., 1, 29.
[4] Chem. News, 34, 193.

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Of the "country rock" surrounding the Oregon beds one large, clean, fresh specimen was received. This was subjected to analysis, and also, through the kindness of Mr. J. S. Diller, to careful microscopic study. The olivine separated from it by Mr. Diller was analyzed also, although the material was not absolutely free from enstatite and chromite, and both analyses are here presented together.

| | Rock. | Olivine. |
|---|---|---|
| Ignition | 4.41 | .57 |
| $SiO_2$ | 41.43 | 42.81 |
| $Al_2O_3$ | .04 | ..... |
| $Cr_2O_3$ | .76 | .79 |
| $Fe_2O_3$ | 2.52 | 2.61 |
| FeO | 6.25 | 7.20 |
| NiO | .10 | .26 |
| MnO | none | none |
| CaO | .55 | none |
| MgO | 43.74 | 45.12 |
| | 99.80 | 99.36 |

It will at once be seen from these data that the rock contains nickel, and that the olivine separated from it contains even a larger proportion. This fact suggests a probable source of derivation for the nickel in the altered beds of ore, and this view is maintained by the microscopic investigation. Concerning the latter, Mr. Diller reports as follows, discussing both the rock and the genthite:

The high specific gravity and dark yellowish green color of the country rock with which the genthite is associated at Riddle, Oregon, at once suggests that it belongs to the peridotites, and such it is proved to be by investigation. It is a holocrystalline granular rock, composed essentially of olivine and enstatite with a small percentage of accessory chromite and magnetite. The olivine predominates, so that the enstatite forms less than one-third of the mass. Both of these minerals are clear and colorless, but may be readily distinguished by their cleavage and optical properties. They are allotriomorphic, i. e. not bounded by crystallographic planes, and do not contain prominent inclusions, excepting a few grains of chromite and magnetite and fine ferritic dust. Notwithstanding the comparatively fresh condition of the rock, to which, according to Wadsworth, the name Saxonite may be applied, it is completely permeated by a multitude of cracks filled with serpentine resulting from alteration. Quartz also results from the metasomatic changes in the saxonite, and wherever the genthite occurs it is always associated with either quartz or serpentine.

The genthite from Oregon varies in color from green to pale apple or yellowish green in reflected light, and is compact with a faint suggestion of fine granular structure. Generally it is dull, but where most compact and traversed by a series of minute fissures or seams of quartz it has a decidedly waxy luster. Under the microscope it usually appears to be an aggregation of irregular grains which have in transmitted light a pale yellowish green to coffee-brown color, and a peculiarly clouded waxy aspect. Where the grains are very thin the genthite may be said to be transparent and isotropic, but the majority of them are only translucent. In the narrow seam of genthite lying between seams of quartz the former is indistinctly fibrous and feebly double refracting; but its system of crystallization could not be definitely determined. In small veins it is free from grains of other minerals, but elsewhere it

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is very intimately commingled with quartz. The relation of the two minerals is shown in the accompanying Fig. 1, in which the shaded portions (3) are genthite,

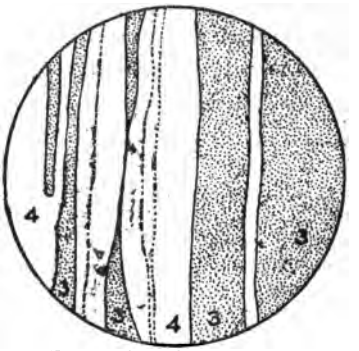


FIG. 1.—Genthite and quartz.

and the clear ones (4) are quartz. The commingling of the two minerals is so intimate as to make it evident that both were deposited from solution in circulating waters. Veinlets of quartz are frequently found cutting across those of genthite, and in general it appears to be true that the latter mineral was laid down first, although it is probable that both were precipitated at about the same time. Although the purest genthite is to be found with quartz, the mineral is more commonly associated with serpentine; and this relation is a most important one in its genetic significance. The accompanying Fig. 2 represents the edge of one of the larger veins of genthite (3),

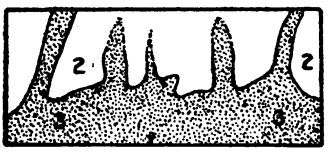


FIG. 2.—Genthite and serpentine.

with numerous veinlets or fissures extending out into the serpentine (2). The tributaries are abundant on both sides of the vein. Fig. 3 shows a vein of genthite (3) in

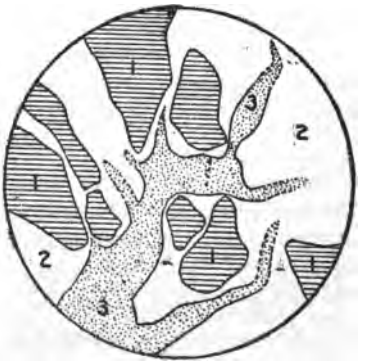


FIG. 3.—Genthite and serpentine with oxide of iron.

the serpentine (2), which envelopes small masses of residuary oxide of iron (1), left by the decomposing olivine. The area represented is only 0.64 of a millimeter in

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diameter and contains no olivine; but less than half a millimeter from the boundary of the vein much olivine still remains, although deeply coated with oxide of iron and serpentine. The branching starting from the vein of genthite, together with the manner in which the arms gradually fade away into the serpentine at once suggests the source from which the genthite has been drawn. The genthite and serpentine are thoroughly intermingled, but the former is generally present in such small quantities as to be overlooked unless it is the object of special research. It occurs in the serpentine directly connected with the grains of olivine from which the serpentine has been derived, and there is every reason to believe that the genthite came from the same source.

In order to secure completer confirmation of the idea that the nickel of the greater silicate deposits is derived from the alteration of nickeliferous olivine, Mr. Diller, at my request, also examined specimens from Webster, N. C., and from New Caledonia. Concerning the Webster genthite Mr. Diller reports that—

It is almost identical with that from Oregon, excepting that it is not so thoroughly intermingled with quartz. The relation of the genthite to the serpentine and the olivine at the Webster locality is exactly the same as at Riddle. The rock at Webster differs slightly from that at Riddle in containing a smaller proportion of enstatite, and belongs to the peridotites to which the name "dunyte" has been applied.

He also finds the New Caledonia mineral to be identical with genthite in its physical properties, and says:

Under the microscope it varies from pale yellowish green to light coffee-brown, and is either completely isotropic or exhibits only faint aggregate polarization. Like the genthite of Oregon it is deposited in layers and cavities thoroughly intermingled with quartz, and in the same thin section may be seen serpentine with traces of olivine and enstatite so disposed as to clearly indicate that the serpentine, noumeaite, and other secondary products have resulted from the alteration of peridotite.

This observation confirms the earlier one of Des Cloizeaux (loc. cit.) who stated that the noumeaite was imbedded in a serpentine rock which appeared to be derived from olivine, and which contained crystals of the latter mineral plentifully disseminated through it. A similar suggestion is made by Mr. H. J. Biddle,[1] who regards the nickel of the Webster deposits as an original constituent of the olivine rock, and cites an experiment of Mr. G. B. Hanna, who found 0.15 per cent. of nickel oxide in a chrysolite from Waynesville, N. C.

So far, the case appears to be clearly and conclusively settled as to the origin of the nickel silicates under discussion. Nickel is almost always present in small quantities in olivines, and T. Sterry Hunt, in reporting genthite from Michipicoten Island[2] calls attention to the fact that the metal is rarely absent from the serpentines, steatites, diallages, and actinolites of the Quebec group. Nevertheless, one other possible source of nickel must be noticed. Roth,[3] in speaking of the genthite from the chrome mines of Pennsylvania, attributes it to the alteration of nickeliferous chromite; and the almost universal association of the

[1] Mineral Resources of the United States, 1886.
[2] Report Geol. Survey of Canada, 1863, p. 506.
[3] Allgem. und Chem. Geologie, vol. i, p. 225, 1879.

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latter mineral with genthite, renders the view deserving of attention. But it must be remembered that chromite alters with great difficulty, while olivine decomposes with extreme ease; and moreover the genthite from Oregon contained no chromium, although that metal was diligently sought for. Furthermore, Mr. Diller examined some of the chromite from the Riddle mines, and found that although it was penetrated by crevices filled with secondary minerals containing genthite, the chromite itself showed no evidence of alteration.

Concerning the other silicates of nickel, described under the names of pimelite, alipite, conarite, röttisite, refdanskite, etc., little need here be said. Some of them are probably similar in origin to the better known genthite, although the conarite and röttisite, which contain small amounts of sulphur and arsenic, probably came from nickeliferous sulphides. For the other minerals above named there is too little evidence upon record to warrant any serious attempt at discussion.[1]

[1] A full discussion of the nickel silicates from New Caledonia may be found in Professor Liversidge's work, entitled "The Minerals of New South Wales, etc.," published by Trübner &Co., in 1888.

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# NATURAL SODA; ITS OCCURRENCE AND UTILIZATION.

By THOMAS MAREAN CHATARD.

The enormous consumption of carbonate of sodium in consequence of the great variety of uses to which it is applied in manufactures and in daily life, has made its artificial production one of the most thoroughly studied branches of chemical technology. The valuable work of Lunge,[1] which is the standard authority on this subject, gives the history of this industry from its slender beginnings to its present vast expansion and shows what energy, ability and capital have been expended in the course of its development.

Of the many methods proposed for the manufacture of carbonate of sodium, but two, the Le Blanc and the ammonia processes, have fulfilled practical requirements and are, at present, contending together for the mastery of the field. So sharp is this competition that in many cases the Le Blanc process can live only through the demand for its by-products—the soda obtained yielding little or no profit—and if the problem of the utilization of the chlorine in the waste liquors of the ammonia process be ever economically solved, the former method must soon become a thing of the past.

Before the discovery of the Le Blanc process the only sources of carbonate of sodium were barilla, or the ashes of certain plants, and a small amount of "trona" or "natural soda" obtained from Hungary and a few African localities. The principal use of soda is in the manufacture of hard soaps, which, in default of this alkali, can be made by adding common salt to the "soft soap" produced by saponification of fats by means of the potash-lye obtained by the leaching of wood ashes. The addition of salt causes the soap to curdle, the sodium of the salt replacing the potassium of the "soft soap" while the residual liquid contains chloride of potassium. Such was the method of soap-making followed at that time, but the increasing cost of potash and of barilla gave a powerful impulse to the artificial soda manufacture which abroad has now become the most important branch of chemical industry.

[1] Sulphuric Acid and Alkali, by George Lunge. Ph.D., three vols., London, 1880.



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Nature has been bountiful in giving us, within our boundaries, sources of soda which await the union of capital and technical skill to become valuable producers of national wealth. These sources of natural soda are the alkaline lakes and "dry deposits" situated in that section of the country lying between the Rocky Mountains and the Sierra Nevada, known as the "Great Basin." Many are well known, having been described by the various Government expeditions and surveys; while some are too weak, too impure, or of too little extent to have a prospective value, others promise good results to well-directed practical development. To aid this, the present investigation has been undertaken by the United States Geological Survey.

This work naturally falls into two divisions—the collection and arrangement of previously existing knowledge and a study of the technical questions involved. As the literature of the subject consists of but few articles, most of which are to be found only in journals inaccessible to those more particularly interested, it has been deemed advisable to bring together, in a compact form, the information we possess concerning foreign localities, both as to their nature and the work done in connection with them. In regard to the study of the technology of the subject, it must be understood that this has its special difficulties, since laboratory experiments on a small scale, no matter how carefully conducted, can rarely reproduce the condition existing in large masses of such material, while the influence of the climate is also a very potent factor. For these reasons a portion of the work was done in the field, and more was contemplated, but unforeseen circumstances have prevented the complete prosecution of this plan, and the results so far obtained are published in order that others may be induced to take up the work and develop it on a practical scale.

## COMPOSITION.

"Natural soda," so called to distinguish it from the soda produced by artificial processes, is the residue obtained by the evaporation of alkaline waters, without the aid of artificial heat. It is composed of sodium carbonate and bicarbonate, in varying proportions, mixed with impurities, mainly sodium chloride and sulphate. In comparing natural sodas from different localities we shall find that they vary widely in composition, so that a process of manufacture developed in one locality, and yielding there a very pure and cheap product, may fail completely when applied without proper modification to the material from another place.

The problem to be solved is the economical production of commercial sodium carbonate by the appropriate treatment of the natural soda, and the means to be employed are, in the main, solution, evaporation and fractional crystallization. By fractional crystallization we mean a methodical stoppage of the crystallizing process by removal of the remaining solution or "mother liquor" from the "crop" of crystals so far

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obtained. This "first crop" may be either the desired material in a purer condition than it was in the original solution or may consist mainly of impurities which we wish to remove.

As the first step in this study it is necessary for us to know the nature and properties of the salts composing natural soda, not only when they are pure, but also when in combination with each other, since the properties and reactions of each salt are modified by the presence of the others in its solution, and the extent of this influence is generally proportionate to the relative amounts of the salts present.

The substances to be considered are, therefore, sodium sulphate, chloride, carbonate and bicarbonate, and in describing them only those characteristics which seem to be of interest in this connection will be mentioned, since the text-books of chemistry, notably the work of Lunge already mentioned, give all needed general information with sufficient fullness.

### SODIUM SULPHATE.

Sodium sulphate $Na_2SO_4$, or anhydrous sodium sulphate, is found in nature as the mineral Thenardite. Combined with ten molecules of water of crystallization or $Na_2SO_4 10H_2O$, it forms the mineral Mirabilite. Both of these minerals, as also the artificial sulphate, are soluble in water, and the solution on being evaporated yields, according to the temperature and other conditions, either anhydrous salt or salt with seven or ten molecules of water of crystallization.

The composition of these salts is as follows:

| | Anhydrous. | With 7 $H_2O$. | With 10 $H_2O$ |
|---|---|---|---|
| $Na_2O$ | 43.67 | 23.13 | 19.25 |
| $SO_3$ | 56.33 | 29.85 | 24.84 |
| $H_2O$ | ..... | 47.02 | 55.91 |
| | 100.00 | 100.00 | 100.00 |

Of the two hydrated salts, the one with 10 $H_2O$ is generally known as crystallized Glauber's salt, and is formed when the solution is evaporated under ordinary conditions. It forms large transparent crystals which effloresce in the air, falling into a white powder and losing all of the water if the air is sufficiently dry. If, however, the solution is made strongly alkaline, by the addition of sodium carbonate, and evaporated at ordinary temperature, the crystals then obtained are anhydrous.[1] That the sulphate is under such circumstances anhydrous is also shown by the numerous analyses of mixed salts given in this paper, notably those on pages 63, 64, as the amount of water there found is insufficient for even the salt with one molecule of water of crystallization or $Na_2SO_4$, $H_2O$, said by Thomsen[2] to be formed under such conditions.

[1] Schulz-Sellack: Journ. für prakt. Chem., series 2, vol. 2, p. 459.

[2] Thomsen: Ber. Deutsch. Chem. Ges., vol. 11, p. 2042.

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The solubility of this salt in water increases with the temperature, 100 parts of water at 0°(32° F.) dissolving 5.02 parts $Na_2SO_4$, while at 33° C(91.4° F.), the point of greatest solubility, 50 parts $Na_2SO_4$ are dissolved. As different observers give different results it is well to state at this point that the solubility of a salt at any given temperature depends on whether we take the salt in its anhydrous condition or as combined with water of crystallization. The experiments of Loewel[1] show this very clearly for sodium sulphate, and it is also true for sodium carbonate. Of course the figures are only true for pure solutions; if other salts are present such as chlorides and carbonates the question becomes very complicated. The results obtained by the series of experiments on the evaporation of Owens Lake water, to be described later, may, however, aid us in forming correct conclusions, but so far we can only say that, from a practical point of view, the sodium sulphate which is always present to a greater or less extent in all alkaline waters and dry deposits is a most unwelcome guest, being of itself comparatively worthless, but by its presence greatly complicating any process devised for the extraction of the valuable carbonate. As will be seen later it is deposited to some extent with the "first crop" of crystals, even when this crop represents but a small portion of the total salts in solution, and, unlike sodium chloride, it has a distinctly deleterious effect upon the quality of the product. It must, therefore, be the aim of the manufacturer to prevent, or at least to control, its deposition as far as practicable, and to attain this result careful and judicious work will be necessary.

### SODIUM CHLORIDE.

Sodium chloride (NaCl) or "common salt," contains 39.39 per cent. sodium and 60.61 per cent. chlorine. It crystallizes in cubes which, when the crystallization occurs on the surface of the solution, usually unite together to build up the well-known "hopper forms." The crystals formed on the bottom are generally incompletely developed, but sometimes, and this is particularly the case when certain other salts are present, the cubes are perfectly formed, transparent and very bright. Other crystal forms and modifications have also been observed.

One hundred parts pure water at 0° C (32° F.) dissolve 35.59 parts NaCl, and this solubility is but little increased by a rise in temperature as at 30°C (86° F.), only 36 parts are dissolved. Even at the boiling point of the saturated solution 109.7° C(129.5° F.) it contains but 40.35 parts. This peculiarity of solubility is of great importance in the practical treatment of the natural soda, since it renders the removal of the chloride a comparatively easy matter, the rate of deposition of the salt being but little influenced by changes of temperature of the solution.

If deposited with the crop it has no other effect than to reduce the percentage of alkali, and therefore the market value of the product,

[1] Loewel: Ann. Chim. et Phys., series 3, vol. 49, p. 32.

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while its presence in the solution up to a certain proportion appears to have a distinctly beneficial action as causing a more complete and satisfactory crystallization of the first crop.

The influence of chloride of sodium on the solubility of carbonate of sodium will be shown under the latter head by the tabulated results of experiments undertaken to determine it.

### SODIUM CARBONATE.

Sodium carbonate or sodium monocarbonate $Na_2CO_3$ is composed of—

| | Molecular weight. | Per cent. |
|---|---|---|
| Soda, $Na_2O$ ..... | 62.0 | 58.53 |
| Carbonic acid, $CO_2$.... | 44.0 | 41.47 |
| | 106.0 | 100.00 |

It is an opaque white salt of a specific gravity of 2.5, and melts at a moderate red heat, losing a small portion of its carbonic acid, this loss occurring even when the salt is heated and cooled in a stream of dry carbonic acid. When fused in a crucible over an ordinary flame the loss of weight at a red heat is about six-tenths of 1 per cent.; as the heat increases so does the loss, so that at a yellow heat up to 1.75 per cent. is lost, but this is regained as the material cools, so that the final loss is that at a red heat. If the salt is fused in a current of air or of steam, the loss is continual and proportioned to the degree and duration of the heating, experiments giving a loss as high as 2.05 per cent.[1] A solution of sodium carbonate, if boiled, undergoes a small but continued loss of carbonic acid, and the same loss occurs if the solution is placed in a vacuum at ordinary temperatures. (Jacquelain.)

Sodium carbonate dissolves in water with evolution of heat. From its solution it crystallizes with 1, 2, 3, 5, 6, 7, 10 and 15 molecules of water; (1) according to the temperature of the solution, and (2) according to whether the solution, prepared at a boiling heat, in cooling down is freely exposed to the air or not.

Of these hydrates the monohydrate ($Na_2CO_3H_2O$), is found in nature as the mineral thermonatrite; "the trihydrated salt ($Na_2CO_3, 3H_2O$), according to Schickendantz, is found as an afflorescence in dry places of the beds of rivers in the Cordilleras;"[2] while the decahydrate ($Na_2CO_310H_2O$), which is the ordinary "crystal soda" of commerce, has been found native by Olzewsky.[3] The anhydrous carbonate $Na_2CO_3$ also seems to occur, as Kayser[4] describes an incrustation which had evi-

[1] Scheerer: Ann. d. Chemie u Pharm., 116, p. 129; Mallard: Ann. de Chimie, series 4, vol. 28, p. 89; Jacquelain: Ann. de Chimie, series 4, vol. 32, p. 193.

[2] Lunge: Sulphuric Acid and Alkali, vol. 2, p. 277.

[3] Olzewsky: Journal für prakt. Chemie, vol. 102, p. 375.

[4] Kayser, W.: Liebig's Jahresbericht der Chemie, 1850, pp. 759, 821.

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dently been formed by the weathering of the clay slate upon which it was found. His analyses of both slate and incrustation are given and are interesting as bearing on the problems of rock decomposition and as showing one of the ways in which "natural alkali" is produced.

| | Slate. |
|---|---|
| $SiO_2$ | 49.87 |
| $Al_2O_3$ | 26.41 |
| $Fe_2O_3$ | 6.95 |
| $Mn_3O_3$ | 1.21 |
| CaO | 2.10 |
| MgO | .87 |
| $K_2O$ | 2.96 |
| $Na_2O$ | 1.61 |
| Sulphur | .39 |
| Carbon | .65 |
| $H_2O$ | 7.05 |
| BaO | tr. |
| | 100.27 |

| | Incrustation. |
|---|---|
| $Fe.CO_3$ | .19 |
| $MgCO_3$ | 3.32 |
| $CaCO_3$ | 1.81 |
| $Na_2CO_3$ | 92.07 |
| $H_2O$ | 1.85 |
| | 99.24 |

Sodium carbonate is most soluble, according to Mulder, in pure water at 32.5° C (90.5° F.), the solution then containing 59 parts $Na_2CO_3$ to 100 parts water, or 37.10 per cent. Hence a solution which has deposited crystals at the boiling point (105° C—221° F.) redissolves them while cooling till the temperature sinks below 32.5°C, when recrystallization begins. The solubility varies very greatly with the temperature; thus at 15.5°C (60°F.) the saturated solution contains 14.53 per cent. at 31.3°C, 30.04 per cent. and at 32°C, 31.78 per cent.

The presence of sodium sulphate or chloride decreases the amount of carbonate which a given amount of water can dissolve, and as the nature and extent of this influence is of importance in studying the conditions attending the separation of the carbonate from the natural deposits and solutions, all of which contain chlorides usually in larger proportions than carbonates, three series of experiments have been carried out and the results are given in the following table.

In series A the NaCl was dissolved in water and the solution was made up to 50cm³. The $Na_2CO_3$ was then added and the whole shaken vigorously, the shaking being repeated at intervals throughout the day. The graduated cylinders containing the solutions were allowed to stand till the next morning, when the mother liquors were filtered from the deposited salts, a perforated crucible with asbestos felt being used for this purpose.

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The volume and temperature of the filtrate were noted, and 25 $cm^3$ were taken for the determination of the specific gravity. This portion was then diluted with water to 1000 $cm^3$, and of this dilute solution portions of 50$cm^3$ each were taken for the determinations. These portions as well as the 1000 $cm^3$ were in all cases weighed, and the results given have been calculated by the factors so found.

In series B the operations were the same, except that the $Na_2CO_3$ was dissolved first, the NaCl being added, in portions of 2.5 grams until a permanent deposit was formed, while for series C a saturated mother liquor of $Na_2CO_3$, $10H_2O$ was employed, 50$cm^3$ being taken for each portion.

| Series No. | In 50$cm^3$. | | °C. | Sp. G. | Per cent. $Na_2CO_3$. | Average. | Per cent. NaCl. | Average. | Total per cent. of salts. |
|---|---|---|---|---|---|---|---|---|---|
| | Na Cl. grams. | $Na_2CO_3$ added. | | | | | | | |
| A1.... | Saturated. | 5.0 | 34.0 | 1.245 | 7.88 | 7.90 | 21.26 | 21.125 | 29.150 |
| | | | | | 7.92 | | 21.24 | | |
| A2.... | 12.5 | 10.0 | 35.5 | 1.294 | 14.83 | 14.85 | 17.29 | 17.265 | 32.115 |
| | | | | | 14.87 | | 17.24 | | |
| A3.... | 10.0 | 15.0 | 32.5 | 1.314 | 18.34 | 18.35 | 14.39 | 14.38 | 32.73 |
| | | | | | 18.36 | | 14.37 | | |
| A4.... | 7.5 | 17.5 | 33.0 | 1.329 | 22.30 | 22.28 | 10.54 | 10.525 | 32.805 |
| | | | | | 22.26 | | 10.51 | | |
| A5.... | 5.0 | 20.0 | 33.0 | 1.340 | 26.36 | 26.36 | 7.01 | 7.015 | 33.375 |
| | | | | | 26.36 | | 7.02 | | |
| A6.... | 2.5 | 22.5 | 33.5 | 1.352 | 29.34 | 29.325 | 3.42 | 3.42 | 32.745 |
| | $Na_2CO_3$ grams. | NaCl added. | | | 29.31 | | 3.42 | | |
| B1.... | 12.5 | 12.5 | 35.0 | 1.309 | 16.67 | 16.665 | 15.46 | 15.455 | 32.120 |
| | | | | | 16.66 | | 15.45 | | |
| B2.... | 10.0 | 12.5 | 35.5 | 1.281 | 14.01 | 14.00 | 17.38 | 17.385 | 31.385 |
| | | | | | 13.99 | | 17.39 | | |
| B3.... | 7.5 | 15.0 | 32.3 | 1.261 | 10.48 | 10.48 | 19.67 | 19.665 | 30.145 |
| | | | | | 10.48 | | 19.65 | | |
| B4.... | 5.0 | 15.0 | 32.5 | 1.237 | 7.14 | 7.145 | 21.41 | 21.42 | 28.565 |
| | | | | | 7.15 | | 21.43 | | |
| B5.... | 2.5 | 17.5 | 33.0 | 1.217 | 3.67 | 3.675 | 24.07 | 24.065 | 27.740 |
| | | | | | 3.68 | | 24.06 | | |
| C1.... | Saturated. | none.... | 31.3 | 1.3287 | 30.07 | 30.045 | ..... | ..... | 30.045 |
| | | | | | 30.02 | | | | |
| C2.... | .. do ..... | 5.0 | 36.0 | 1.3435 | 26.59 | 26.595 | 7.26 | 7.265 | 33.860 |
| | | | | | 26.60 | | 7.27 | | |
| C3.... | ...do ..... | 7.5 | 29.5 | 1.3114 | 19.415 | 19.416 | 13.08 | 13.08 | 32.496 |
| | | | | | 19.417 | | 13.08 | | |
| C4.... | .. do ..... | 10.0 | 29.5 | 1.3139 | 18.59 | 18.595 | 14.62 | 14.62 | 33.215 |
| | | | | | 18.60 | | 14.62 | | |
| C5.... | ...do ..... | 12.5 | 30.0 | 1.3146 | 18.81 | 18.825 | 14.48 | 14.47 | 33.395 |
| | | | | | 18.84 | | 14.46 | | |
| C6.... | ...do ..... | 15.0 | 30.0 | 1.3204 | 19.29 | 19.295 | 14.17 | 14.16 | 33.455 |
| | | | | | 19.30 | | 14.15 | | |



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In each of the experiments here tabulated, with the exception of C1 there was a considerable deposit of salts consisting of a mixture, in varying proportions, of the two salts employed, and the composition of the deposit can be calculated by the difference between the amounts originally taken in each case and those in solution.

It will be observed that in the A series the point of equilibrium in the percentages of the two salts in solution lies between A2 and A3, probably near to the point where equal weights of NaCl and $Na_2CO_3$ would be taken. This is substantially proved by B1 where 12.5 grams of each salt were used and the amount of $Na_2CO_3$ was 1.21 per cent. higher than that of the NaCl.

The salts, however, do not appear to dissolve in proportion to the amounts taken, the variations being greatest in the A series where the $Na_2CO_3$ was added to the solution of the NaCl; whereas in the B series, the $Na_2CO_3$ was first dissolved and the NaCl added the variations are much smaller. We may therefore conclude that if a mixture of these two salts is treated with an amount of water insufficient for complete solution, the amount of each dissolved will be approximately proportionate to the quantity present but that the approximation is not very close.

Series C shows the effect of the addition of increasing proportions of NaCl to a saturated solution of $Na_2CO_3$. 50cm³ of this solution at 31.3° C. weighs 66.3424 grams and contains 19.9224 grams $Na_2CO_3$, or, as given in the table, 30.045, per cent. The table shows that the addition of 7.5 grams NaCl gave the best result, but as some of it remained in the deposited $Na_2CO_3$, a less quantity might have been advantageously taken, say 6.64 grams or one-third of the weight of the $Na_2CO_3$ in solution. Had this been done we should probably have had little more $Na_2CO_3$ left in solution and that deposited would have been purer. If the amount of NaCl is increased, the excess as shown, remains undissolved and the character of the solution suffers but little change. The practical bearing of these results will be more apparent when we come to that portion of this paper treating of urao or the combination of sodium monocarbonate with sodium bicarbonate.

### SODIUM BICARBONATE.

Sodium bicarbonate, $NaHCO_3$, contains—

| | Per cent. |
|---|---|
| Soda, $Na_2O$ | 36.94 |
| Carbonic acid, $CO_2$ | 52.36 |
| Water, $H_2O$ | 10.70 |
| | 100.00 |

It is formed by the action of $CO_2$ on $Na_2CO_3$, hence is always produced when a solution of the latter salt is exposed to the air. At the ordinary pressure of the atmosphere the reaction is a slow one, but if pure $CO_2$ at a pressure of 30 pounds to the square inch is used the conversion is rapid.

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The salt occurs in monoclinic tables usually combined into crusts. It has a somewhat alkaline taste; if entirely free from $Na_2CO_3$ it does not change turmeric, but reddens blue litmus. The best test for its purity, according to Hager, is calomel; 0.5 gram calomel mixed with 1 gram $NaHCO_3$ and 1.5 gram water and shaken up does not blacken in 24 hours in the absence of monocarbonate, but in its presence it turns more or less gray. In moist air or if moistened with water the salt loses $CO_2$, the more quickly the higher the temperature. Hence if a solution of bicarbonate is heated the bicarbonate is gradually destroyed and monocarbonate remains, which has an important bearing upon the problem of the economic treatment of natural soda.

$NaHCO_3$ is much less soluble in water than $Na_2CO_3$, 100 parts of water at 15.5°(60°F) dissolving only 8.9 parts or 8.17 per cent. The solubility is much diminished by the presence of sodium chloride or sulphate, or a mixture of both. A saturated solution of sodium chloride dissolves hardly any of the salt, a fact of great importance, since upon it is based the ammonia process for the manufacture of soda.

### SODIUM SESQUICARBONATE.

Sodium sesquicarbonate, $Na_4H_2C_3O_9$, so called because the old dualistic formula was $(NaO)_2(CO_2)_3$ is described in all chemical works which treat the subject of the sodium carbonates at all fully. It is said to exist in nature as a mineral to which the name trona has been given and has been prepared artificially by R. Hermann[1] and Winkler.[2] Other chemists also claim to have obtained it. It represents a combination of one molecule of $Na_2CO_3$ with two molecules of $NaHCO_3$ or $Na_2CO_3, 2NaHCO_3$, which may also be written $Na_4H_2C_3O_9$. My own experiments, which will be given in detail further on, not only failed in reproducing this salt, but also throw considerable doubt upon its actual existence as a definite chemical substance, and not as a mixture of the two carbonates accidentally formed in these proportions.

There is, however, a very definite combination of the two carbonates, which occurs, as will be shown, widely distributed in nature and which bears the mineral name *urao*. This salt is composed of one molecule of sodium monocarbonate and one of sodium bicarbonate, plus two molecules of water of crystallization, or $Na_2CO_3, NaHCO_3+2H_2O$, or $Na_3HC_2O_6, 2H_2O$. It is very easily produced artificially, in a well crystallized condition, and is most important in this connection, since by its chemical behavior it gives the key to a rational economic process whereby the natural sodas can be made available for use in the arts.

For this reason it will be made the subject of a special section of this paper, but before taking it up we will briefly consider the principal localities of natural soda throughout the world and the character of the salts produced by them. In this manner a better idea of the extent

[1] R. Hermann: Jour. für prakt. Chemie, vol. 26, p. 312.

[2] Winkler: Buchner's Repert. für Pharm., vol. 48, p. 215.

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and difficulty of the problem can be obtained, while a mass of matter at present scattered through the various journals is brought together for comparison.

## LOCALITIES AND MODE OF OCCURRENCE.

As a dry climate is the prime factor for the formation of deposits of natural soda, or of concentrated waters heavily charged with it, and as such climatic conditions exist in many parts of the world, there are numerous places where this material has been found or may reasonably be looked for. A complete list of these occurrences is not available, nor would it have any special value, and in speaking of the foreign localities only those will be described where the material is being utilized or where the local conditions are of interest for comparison with our home sources of supply.

### HUNGARY.

In Hungary natural soda is found in many places, especially near the town of Szegedin.[1] It occurs as an efflorescence on the surface of moist places, the snow-white crust often extending for miles. The crude soda or "szekso" is collected by scraping the surface, the best time for this operation being the early morning before sunrise, particularly in the spring and when much dew has formed, as the material collected during the day is considered to be poorer in salts. As the crust is thin and much of the soil is gathered with it, the product is a grayish white earth; this is sold to the refiners, whose only test for its value was, at the date of the description, the sharpness of the taste. Moser[2] gives the following analysis of the szekso as gathered:

| | |
|---|---|
| Soda, $Na_2O$ | 8.03 |
| Potash, $K_2O$ | 3.12 |
| Lime, CaO | 2.72 |
| Magnesia, MgO | Trace. |
| Alumina, $Al_2O_3$ | 2.33 |
| Sulphuric acid, $SO_3$ | 3.48 |
| Silica, $SiO_2$ | 1.04 |
| Water, $H_2O$ | 15.50 |
| Insoluble (sand, etc.) | 54.99 |
| Carbonic acid, $CO_2$ | 8.79 |
| | 100.00 |

In the refineries the earth is leached until the soda taste is no longer perceptible, giving a dark-brown solution containing sodium carbonate, sulphate, and chloride; this is evaporated to dryness and calcined, the mass being ultimately heated to complete fusion, and, when partly cooled, drawn from the furnace. The product when cold is broken up and sent to market.

[1] Werner: A. Jour. f. prakt. Chemie, vol. 13, 1838, p. 127.
[2] Moser: Liebig's Jahresbericht, 1859, p. 812.

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Schapringer[1] gives the following analyses of two samples of this soda. No. 1 is said to have been made by evaporating the leachings and drying the product in the air, while No. 2 is said to have been obtained by calcining No. 1:

| | No. 1. | No. 2. |
|---|---|---|
| Sodium carbonate, $Na_2CO_3$.... | 28.87 | 40.25 |
| Sodium chloride, NaCl..... | 31.00 | 53.93 |
| Sodium sulphate, $Na_2SO_4$ ..... | .13 | .45 |
| Calcium carbonate $CaCO_3$..... | .39 | 1.54 |
| Sand, clay, etc..... | .41 | 1.45 |
| Water ..... | 39.04 | 2.09 |
| Loss ..... | .16 | .29 |
| | 100.00 | 100.00 |

It is difficult to understand these analyses, since No. 1, if air-dried, could not contain the amount of water here given, and if calcined could not yield a product of the composition of No. 2 which is, at best, very impure and of but little value. The analysis of the szekso shows no chlorides, which is also remarkable, when we consider the origin of this soda, which has been discussed by Szabo and Moser.[2] According to them the sandy soil contains a large proportion of soda minerals which decompose through the joint action of carbonate of lime, water, and air. The lime furnishes carbonic acid to the soda which is dissolved in the water with which the ground, in winter, is saturated. As the summer approaches and the ground becomes warmer, the decomposition increases, while the water rising to the surface and there evaporating leaves its salts behind.

Owing to the rude methods of refining, with consequent variations in composition, and the increasing cost of collection, the Hungarian soda has not been able to compete with the artificial product, and now supplies only a limited local consumption in the manufacture of the celebrated Szegedin soap. Its history, however, is interesting, since we have in the West many occurrences of soda similar to those of Hungary, and it would seem at first sight as though they could be utilized; but if in a country of such low wages as Hungary the cost of collection is too great we can hardly look for much success in attempting similar processes at home, unless we can find deposits comparatively pure and of considerable thickness. In default of such, we can expect satisfactory results only from the waters of the soda lakes, in which nature, having performed the leaching process, has collected and concentrated the salts.

[1] Schapringer: Dingler, Polyt. Jour., vol. 189, p. 495.

[2] Szabo, J., and Moser, J.: Wagner's Jahresber., 1862, p. 223.

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EGYPT.

The soda lakes of Egypt have been described by D'Arcet[1] and by Russegger.[2] They are nine in number, in the Desert of St. Macarius, sixty miles northwest of Cairo and about thirty[3] miles from the Nile, and are situated in a small valley running northeast and southwest. The largest, Nehelé, is five miles long by one-and-a-half wide, with a maximum depth of 20 feet. On the eastern side of the valley are a number of weak brine springs (some, indeed, being fresh) which feed these lakes in which, having no outlet, the concentration is continual, varied only by the annual rise and fall. Russegger observed that the lakes rise when the Nile is falling and fall during its rise, and ascribes this partly to the rains which occur during the decrease of the river and partly to the supposition that the rise of the river is sufficient to overflow the divides of the clay formation which underlies the desert sand, and the water then flows through the sand to the lowest points of the valley in which are the lakes. As, however, it takes much time for the water to travel that distance, the lakes are not reached, and therefore do not rise, until the end of the high-water season.

The surface of the country is the desert sand, under which is a layer of blackish-gray clay, 20 feet thick, resting upon a tertiary sandstone. This clay is strongly impregnated with chloride of sodium and carries much gypsum, the quantity of both salts being much greater in the lower than in the upper part; it also contains much carbonate of lime. The gypsum is either scattered in single crystals through the whole mass of the clay, or, especially in the lower part, interstratified with it in thin layers intermixed with desert sand and common salt, forming a kind of gypsum sandstone.

The lakes, formed by the leaching out of the soil, are therefore strong solutions of chloride of sodium containing in addition varying proportions of carbonate and sulphate of sodium. During the dry season, the smaller lakes dry up entirely, leaving on the bottom a salt crust of the composition of the entire lake; the larger lakes, on the other hand, do not dry up, but, as they become more concentrated, deposit salt crusts the composition of which depends upon the percentage of carbonate of sodium in the water.

In some of the lakes, bottom deposits are said to have gradually formed whose upper portion, 16 feet thick, consists essentially of sodium chloride, whilst the lower one, 17 feet thick, contains sodium carbonate. The above mentioned crusts, which are 15 to 18 inches thick, are pushed off by means of poles and spades, spread out to dry on the banks, and carried in baskets to the Nile, whence the salt is shipped to

[1] D'Arcet: Comptes rendus, September, 1845, vol. 10. Dingler Polyt. Jour., vol. 98, p. 159.

[2] Russegger: Karsten's Archio, vol. 16, 1842, p. 380.

[3] Lunge: Sulphuric Acid and Alkali, vol. 2, 1880, p. 285—gives "five miles" as the distance from the Nile. He also quotes "Landerer, Wagner's Jahresb. 1858, p. 68," in this connection, but the volume for that year does not seem on examination to have anything by this author or on the subject.

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other parts. It is called "latroni" in the Levant and in Greece; the Egyptians use it to soften their very hard drinking water by precipitating its lime and magnesia salts, the water being afterwards filtered. Its principal use is in Crete for soap making. From Alexandria yearly about 2,500 tons are exported.[1]

This soda has been analyzed by Remy,[2] who describes the sample as bright gray, crystalline, effloresced on surface, slowly soluble in cold water, more rapidly in hot, leaving a little residue partly soluble in hydrochloric acid. The analytical results are as follows:

| | |
|---|---|
| Sodium chloride, NaCl | 8.160 |
| Sodium sulphate, $Na_2SO_4$ | 2.147 |
| Sodium silicate, $Na_2SiO_3$ | .288 |
| Sodium sesquicarbonate, $Na_4H_2C_3O_9$ | 47.292 |
| Sodium carbonate $Na_2CO_3$ | 18.430 |
| Calcium carbonate $CaCO_3$ | .200 |
| Water | 19.669 |
| Insoluble | 4.106 |
| | 100.292 |

ARMENIA.

As described by Abich,[3] the lakes of the Araxes plain in Armenia lie in the volcanic region of Ararat and show a great variety of composition. The lake of Tasch-Burun is situated on "the most distant of the lava masses which have broken out at the northwestern base of the Great Ararat," and its water carries 6.66 per cent. of salts, mainly sodium chloride as shown by analysis No. 1. Analysis No. 2 gives the composition of the crusts which are deposited on the shore in hot weather; these attain a thickness of a half-inch and are of a reddish color.

Other lakes are found southeast of Little Ararat among the volcanic lavas of this mountain. One of these lakes, remarkable for the reddish color of its water, lies on the left side of the valley close under the steep declivities of the greatest heights of the Gundusdag range which is formed of sandstone, dolomite, slates, and limestone and is broken through and shattered by a red quartz-porphyry. The surface of the country is a whitish clay, supporting a strong growth of soda plants.

The shore of this lake, which is about a mile in circumference, is very soft, so that walking is difficult, and is covered with crusts of a hard reddish salt having a laminated fracture. The crusts extend out upon the surface of the lake and portions are floating upon it, so that the whole looks as though it were about to freeze. Soundings showed that crusts had also formed on the bottom, apparently covering the whole of it. The water contains 30.63 per cent. of salts, the composition of which is shown by analysis No. 3, while No. 4 is the composition of the bottom crusts, and No. 5 of the floating portions.

[1] Lunge: Sulphuric Acid and Alkali, vol. 2, p. 286.
[2] Remy: Journal für prakt. Chemie, vol. 57, p. 321.
[3] Abich: Jour. für prakt Chemie, vol. 38, p. 4.

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The heavy bottom crusts are described as being composed of successive layers, each of which is a very solid radiated aggregate of crystals; the red coloring matter is deposited between the layers, which adhere closely together. The floating crusts have nearly the same composition and structure, but the layers are much thinner and the salt is almost white. The analyses are remarkable as showing that not only the sulphate but also the carbonate has crystallized almost free from water. Abich concludes that this is due to the formation of a "double salt" of sodium sulphate and carbonate, for which he proposes the mineral name "makite." In the vicinity of this "red lake," are a number of small pools of a wine-yellow color, but without salt crusts. The water of one of these contained 34.74 per cent. of salts of the composition of analysis No. 5. Other lakes are mentioned in the original paper, but the waters were poorer in sodium carbonate and sulphate and richer in sodium chloride.

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| | Tasch-Burun. | | Red Lake. | | | Yellow pool. |
| | Water. | Crusts. | Water. | Crusts. | | Water. |
| | | | | Bottom. | Floating. | |
| Sodium carbonate, $Na_2CO_3$ | 14.71 | 22.91 | 12.08 | 18.42 | 16.09 | 68.90 |
| Sodium sulphate, $Na_2SO_4$ | 10.36 | 16.05 | 18.18 | 77.44 | 80.56 | 15.55 |
| Sodium chloride, NaCl | 74.61 | 51.49 | 69.73 | 1.92 | 1.62 | 15.50 |
| Water, $H_2O$ | ..... | 9.88 | ..... | 1.18 | .55 | ..... |
| | 99.68 | 100.33 | 99.99 | 99.96 | 98.82 | 99.95 |

The views of Abich as to the mode of formation of these salts will be given in the section treating of the origin of natural soda.

### OCCURRENCE OF URAO IN VENEZUELA, SOUTH AMERICA.

This locality is described by Palacio Faxar[1] as being in a valley named La Lagunilla in the province of Maracaibo, 48 miles from the city of Merida. In the center of this valley, the soil of which is said to consist of limestone, lies a little lake which in the rainy season has a length of 210 meters and a breadth of 106. Although its greatest depth is not over 3 meters, it never dries up entirely even in the driest seasons. The water is yellowish-green, has a soapy feel, an alkaline taste, and a peculiar smell. During the hot season a salt crystallizes on the bottom. This salt, called urao, is collected every two years by the Indians of the neighborhood, who obtain from 100,000 to 160,000 pounds, according to the demand, which is for the manufacture of *mo*, a dried extract of tobacco used by the natives as a stimulant.

[1] Faxar: Ann. de Chimie, ser. 2, vol. 2, p. 432. Also, Pogg. Ann., vol. 7, p. 101.

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The Indians obtain the salt by diving for it, and the peculiar manner in which this is done is thus described by Boussingault:[1]

To collect the urao, the Indians make an excavation on the bottom of the lake, several meters in extent, and plant therein a stake 14 to 16 feet long, the upper end of which reaches above the surface of the water. When this is accomplished an Indian resting upon this stake places the end of a second one upon the deposit and holds it at a certain inclination. As soon as this is done, a second Indian glides down the inclined stake, plunges beneath the surface of the water and after the lapse of a few minutes returns with a portion of the salt. According to the information we have received, the deposit of urao, which is not very thick, is covered by a layer of material containing crystals of calcite. Above this is a bed of ooze, one meter in thickness.

The excavation spoken of in the beginning of this extract is apparently made for the purpose of removing these upper layers; the crystals of so-called calcite were later shown to be gay-lussite $Na_2CO_3,CaCO_3+5H_2O$; and the inclined pole is used to enable the diver in such a dense solution to reach the bottom. Concerning this water, Boussingault very curiously says: "The water of the lake is only slightly saline; animals drink it with pleasure."

As the water is necessarily a strong alkaline mother liquor, often completely saturated, it is evident that this statement is incorrect. Faxar (loc. cit.), more accurately says of the divers: "Their death is inevitable if they swallow a certain quantity of the water."

He also says that the action of the water reddens the hair of the divers.

The Urao is described by Boussingault as "crystallized in prismatic needles arranged in radiating masses; a little softer than calcite. Taste alkaline; does not effloresce." His analysis is as follows:

| | |
|---|---|
| Carbonic acid, $CO_2$ | 39.00 |
| Soda, $Na_2O$ | 41.22 |
| Water, $H_2O$ | 18.80 |
| Impurities | 98 |
| | 100.00 |

NORTH AMERICAN LOCALITIES.

The various exploring and surveying expeditions sent by the Government into the region of the Great Basin have to some extent examined and reported upon the alkaline deposits and lakes lying within the range of their labors. Private prospectors, also, recognizing the future value of these salts, have not overlooked them, especially when the rapid development of the borax industry caused every accessible salt-flat or marsh to be scrutinized and tested for that substance. In this way natural soda has been found in many places, but the absence of the necessary transportation facilities has, until lately, rendered any plan for the utilization of the soda a matter of the future.

Within the past few years the railroad facilities through this region have greatly increased and are continually extending, so that some of

[1] Boussingault: Ann. de Chimie, ser. 2, vol. 29, p. 110.

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the more promising localities are within easy reach. The consumption of soda in this country is already great and steadily growing larger, and it remains for technical skill, supported by capital, to develop these resources and to convert a hitherto valueless, even obnoxious, material into a source of wealth. That this can be done there is no reasonable doubt; that it will be done should not be doubtful to any one who knows the activity and enterprise of our people. The advantages flowing from a successful prosecution of such an undertaking are reaped not only by the operators, but also by the entire section of country in which the work is carried on, and as, except in some favored localities, nature has not been bountiful to this region, well-directed art must extend its aid.

The expense of the necessary preliminary investigations is considerable, but without these capital can hardly be expected to take any decided steps. A great deal of information, in the aggregate, has been gathered by various observers, but scattered as it is through various publications it is not readily available. It has therefore been deemed advisable to bring this knowledge together so that we may have a proper starting point for future work.

In proceeding to describe the localities within the boundaries of the United States only those concerning which we have reliable information will be considered, and it will be found that their number and variety are great enough to furnish types for any others which future investigators may bring to notice.

*Wyoming.*—Along the line of the Union Pacific Railway in the Territory of Wyoming are several places where natural soda is found. The best description of these is the following, from a paper on "Glass Materials," by Jos. D. Weeks, published by the Geological Survey in the "Mineral Resources of the United States, calendar year 1885":

The soda property generally known as the "Union Pacific Lakes" lies about 13 miles nearly due south of Laramie and is reached by a branch of the Union Pacific Railway. The property embraces some 2,000 acres, including five "lakes," in all but one of which the soda is solid. The lakes are connected, and seem to drain one into another. All of the soil near Laramie is more or less impregnated with the sulphate of soda, and the common sources, it is believed, are springs, water from which bears large percentages of soda salts.

The physical condition of the soda in the lakes varies much with the season. In wet years the soda is almost fluid, while in dry years, in all but one of the lakes, it is solid and in this one it occurs as a saturated solution. In the solid lakes the soda contains many thin layers of mixed clay and soda. Analysis of a sample of this mixture shows:

*Analysis of deposits of soda salts at Laramie, Wyo.*

| | Per cent. |
|---|---|
| Iron, lime magnesia | 22.33 |
| Alumina, soda, hydrochloric and sulphuric acids | 40.82 |
| Silica | 36.85 |
| Organic matter | traces. |
| | 100.00 |

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The soda when taken pure contains large quantities of water, which fact interferes seriously with its employment in the manufacture of sodium hydrate.

Its composition only varies slightly, and the following may be taken as typical analyses:

*Average analysis of soda deposits near Laramie, Wyo.*

| | No. 1. | No. 2. | No. 3. |
|---|---|---|---|
| | *Per ct.* | *Per ct.* | *Per ct.* |
| Sulphate of soda..... | 44.55 | 41.41 | 39.78 |
| Water ..... | 54.98 | 54.79 | 59.66 |
| Insoluble matter..... | .47 | 3.80 | .56 |
| | 100.00 | 100.00 | 100.00 |

These lakes are the only ones from which soda is being taken for use.

The soda works near Laramie were built by the Union Pacific Railway and leased to Mr. Howard Hinckley. The process used is the old "black ash," with stationary furnace. The capacity of the works is about 2 tons of sodium hydrate per day. The capacity of the furnace is 3½ tons of sodium sulphate per day. Rescreened coal from the Rock Spring Mine is used and the limestone necessary is obtained near Laramie. The "black balls," formed of the fused soda, coal and lime, are broken up and washed in four lixiviating pans, and the liquor is then taken to two settling vats. Thence it is drawn to the "causticizer," which is a large circular tank in which are two perforated vessels containing caustic lime, around which the solution of sodium carbonate is agitated. After the causticising the liquor is passed through three long circular iron settlers. The clear liquor is then drawn to the "V-pan," where waste heat is used to aid the evaporation of the solution. The slightly concentrated liquor is then drawn to the "boat pan," which is set upon the reverberatory furnace. The evaporation is then continued as long as possible, and the now concentrated solution is then drawn to another room into the "finishing pot." This is a large cast-iron pot set directly over a furnace. Here all remaining traces of water are driven off at a low red heat. The hydrate at this stage is generally black and small quantities of niter are added to the fused mass to whiten it. The hydrate is then ladled into sheet-iron vessels and shipped. Some of the Laramie caustic soda has been used by the Denver Soap Company, which reports favorable results from its use. The works at Laramie are not well adapted to the most economical handling of the soda. Improvements are now being made by which the number of men employed will be greatly reduced and the composition of the "black balls" be made more uniform.

When the soda works were first begun it was supposed that the natural occurrence of the material as a sulphate, rendering unnecessary the reduction of the chloride to the form of a sulphate, would greatly decrease the ultimate cost of the caustic soda; but it was found that the very large quantity of water present in the soda as it comes from the lakes, more than offset, by the trouble and delay it cost in the furnaces, the gain in the natural form of the soda.

The Laramie works produced from July to January, 1885, about 30 tons of caustic soda. Defects in the plant have caused great delay and loss of some of the caustic soda, and it has been decided to close the works until alterations now being made can be completed. The lessee of the works states that good reports of the caustic soda have been made by users of it.

The "Donney" soda lakes are situated about 18 miles southwest of Laramie and are three in number covering, with the land included, approximately 520 acres. In one lake the deposit is 11 feet thick; in the others it is 5 to 6 feet. The soda from these lakes is similar to that from the Union Pacific lakes and there seems to be an underground connection between the two groups. In boring an artesian well near

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these lakes to prospect the underlying strata, a brine was obtained which upon analysis showed—

*Analysis of brine from near the Donney Lakes.*

| | Grains per gallon. | Per cent. |
|---|---|---|
| Sodium chloride | 2002.0 | 2.86 |
| Sodium sulphate | 777.2 | 1.10 |

The large percentage of salt is very curious, as only traces of it are found in these lakes.

The soda deposits in Carbon County are situated in the Sweet Water valley, near Independence Rock, and are nearly 50 miles due north of Rawlins. These deposits contain both carbonate and sulphate of soda, and are generally known as the "Dupont Lakes." The lakes are four in number, and vary from 6 to 2,000 acres in area, and are held by United States patents in the name of L. Dupont. There are five claims known as the "New York Soda Mine," 160 acres; the "Philadelphia," 80; the "Omaha," 20; the "Wilmington," 160, and the "Wilkesbarre," 20. The Omaha soda mine includes 20 acres, of which 5 are covered with carbonate and sulphate of soda, mixed with a little chloride of sodium and sand blown in from the surrounding soil. Several bore-holes were put down and show an average thickness of about 6 feet.

*Amount of $Na_2Co_3$ contained in the samples.*

| | | |
|---|---|---|
| No. 1, 3½ feet from surface | per cent. | 24.62 |
| No. 2, surface | per cent. | 41.55 |
| No. 3, surface near shore | per cent. | 32.42 |
| No. 3, water | pounds per gallon. | 1.33 |

A fused sample showed 52.23 per cent. of carbonate of soda. A fuller analysis of a sample taken from the surface showed:

*Analysis of surface soda from Carbon County, Wyo.*

| | |
|---|---|
| Moisture | 9.01 |
| Insoluble | 2.61 |
| Sulphate of soda | 25.75 |
| Chloride of sodium | 2.13 |
| Carbonate of soda | 30.62 |
| Bicarbonate of soda | 30.09 |
| | 100.21 |

Another sample from near the surface contained 56.3 per cent of water:

*Analysis of dry salt.*

| | Per cent. |
|---|---|
| Chloride of sodium | 0.65 |
| Sulphate of soda | 59.29 |
| Carbonate of soda | 27.60 |
| Insoluble matter | 1.20 |

The variations and the proportions of carbonate and sulphate of soda are shown by the following table, the samples having been dried:

| Samples. | NaCl. | $Na_2SO_4$. | $Na_2CO_3$. |
|---|---|---|---|
| | *Per cent.* | *Per cent.* | *Per cent.* |
| Five feet below surface | 0.979 | 64.05 | 15.60 |
| Do | 0.32 | 65.08 | 16.70 |
| Surface | 0.81 | 17.02 | 80.60 |

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The Wilkesbarre claim is about one mile west of the Omaha, and the soda is in solution. Samples of this solution showed by analysis:

| | Per cent. |
|---|---|
| No. 1, $Na_2CO_3$ grains per gallon— | 3,728=6.39 |
| No. 2, $Na_2CO_3$ grains per gallon— | 4,905=8.40 |

The Wilmington claim is located one-quarter of a mile west of the Wilkesbarre, and covers 160 acres. The soda here is also in solution. Its depth has never been determined. It has been sounded with a 40-foot rope without finding bottom in the center. A sample of this solution contained 2,343 grains per gallon (4.01 per cent.) A sample which had crystallized out by cold, when dried showed:

| | |
|---|---|
| Chloride of sodium | 1.83 |
| Sulphate of soda | 39.04 |
| Carbonate of soda | 59.00 |
| Insoluble matter | 9.23 |

The New York and Philadelphia are both upon one lake, which is solid, and is 4 miles west of the Wilmington. Two bore-holes have been put down in this lake. One, at a distance of 50 feet from the shore, showed 4 feet of soda; the other, at a distance ot 230 feet from the shore, passed through 14 feet of solid soda without touching bottom. Three samples taken from this lake showed as follows:

| | No. 1. | No. 2. | No. 3. |
|---|---|---|---|
| Chloride of sodium | 1.83 | 2.04 | 2.52 |
| Sulphate of soda | 71.37 | 44.77 | 72.40 |
| Carbonate of soda | 3.10 | 5.00 | 5.10 |
| Insoluble matter | 22.82 | 47.50 | 19.03 |
| | 99.12 | 99.31 | 99.05 |

Fifteen miles from these soda deposits good limestone, containing 2 per cent of magnesia, occurs in the Seminoe mountains. Near the limestone is a good 8-foot vein of coal. A comparison of the analyses from the Donney and Union Pacific lakes and those of the Dupont lakes show how much greater the percentage of carbonate of soda in the latter is. The Sweet Water country is still out of the reach of transportation, and until a railway is built in this direction these soda deposits must remain undeveloped.

The Wyoming occurrences are typical sulphate deposits, and in many respects resemble those of Armenia, already described. Although they all contain more or less carbonate, yet, so far as we now know, it is not possible to extract the carbonate economically by natural crystallization processes. Under the most favorable circumstances the use of artificial heat is necessary, and, as stated above, the native sulphate, owing to the large proportion of water, has no advantage in point of cost and ease of working over the artificial. Careful and systematic study and experiment will doubtless, however, develop a good commercial method for the treatment of this material, since fuel can be easily obtained at a steadily decreasing cost, and transportation facilities are becoming greater.

Proceeding westwardly from the Wyoming deposits one finds numerous occurrences of salts more or less alkaline in character. Descriptions and analyses of many of these are given by King[1] and Russell;[2] but

[1] King: Geol. Expl. 40th parallel, vols. 1 and 2.

[2] Russell: Geol. Hist. of Lake Lahontan U. S. Geol. Survey, Mon. No. 11.

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most of them are only thin efflorescences or incrustrations, and, so far as we know, none have any commercial value until we reach

*The soda lakes at Ragtown, Nevada.*—These remarkable alkaline lakes or ponds are described at length by King in the work just cited,[1] also by Russell, Monograph, 11, pp. 73–80. From the latter report the following extracts are taken:

On the Carson desert, about 2 miles northeast of Ragtown, are two circular depressions that are partially filled with strongly alkaline waters and known as the Soda Lakes or Ragtown Ponds. * * * The larger lake is 268.5 acres in area. * * * The rim in its highest part rises 80 feet above the surrounding desert, and is 165 feet higher than the surface of the lake which it incloses. The outer slope of the cone is gentle, and merges almost imperceptibly with the desert surface; but the inner slope is abrupt, and at times approaches the perpendicular. A series of careful soundings gives 147 feet as the greatest depth of the lake. The total depth of the depression is therefore 312 feet, and its bottom is 232 feet lower than the general surface of the desert near at hand.

The walls encircling the lake exhibit well exposed sections of stratified lapilli mingled with an abundance of angular grains, kernels and masses of basalt, some of which are 2 and 3 feet in diameter, and scoriaceous, especially in the interior. * * * The form of the cones and the nature of the materials of which they are composed leave no doubt this is a crater ring, viz, a low cone of eruption containing a large crater. That the cones were not formed during a single eruption, but have a long and complicated history, and are perhaps sublacustrine in their origin, is shown by the alternation of ejected and sedimentary materials in the crater walls.

"The smaller lake," according to Hague, "in most of its features, bears a close resemblance to the one just described and from which it is separated by a narrow ridge only an eighth of a mile wide. It has the same crater-like basin, but the banks are not more than 60 or 70 feet in height and the lake, even in spring, is scarcely more than one-fifth of a mile in diameter. There is no supply of fresh water from the surface, and at the time of our visit, in August, the water was much more dense than in the larger lake. Over a great part of the surface was found a thick incrustation of trona strong enough to bear up a man, under which is a greenish slime and occasional pools of water. One characteristic feature of the shore is the green and purplish tints of the moist sands, which, upon being dried, present the usual earthy colors."

The trona from the small soda lake, upon being subjected to analysis yielded the following:[2]

| | |
|---|---|
| Sulphate of soda | 0.99 |
| Chloride of sodium | 1.10 |
| Carbonate of soda | 66.27 |
| Water and free carbonic acid | 28.83 |
| Insoluble residue | 2.81 |
| | 100.00 |

[1] Vol. 1, p. 510—513; vol. 2, p. 746—750.

[2] Hague: King's Rep. 40th Parallel, vol. 2, 1877, p. 749. Russell (op. cit., p. 73., note) says: "The smaller lake (in 1882) had been so changed by excavation and the construction of evaporating vats that its original form had been destroyed. Its surface is 20 feet higher than the larger lake and 65 feet below the general desert surface. The highest point on the crater rim is 80 feet above the bottom of the depression."

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Hague also says of these lakes (op. cit., p. 746): "they lie below the level of the plain, in which are probably ancient craters, and are not observed until just before reaching the brink." King (op. cit., vol. 1, p. 512) considers "that during the period of the occupancy of this region by Lake Lahontan * * * these crater-like lakes were points of extremely powerful springs deriving their great activity from volcanic sources," and gives his observations at Mono Lake, to which we shall refer later.

Russell, on the other hand, says (p. 74):

The hypothesis that the craters were formed by the action of extremely powerful sublacustrine springs, as advanced by King, would not account for the nature of the material forming the crater walls, nor the presence of the numerous volcanic bombs that depress the strata on which they rest. If the cavities owed their origin to springs of very great magnitude rising in the bottom of Lake Lahontan, it is evident that the outflowing waters would have cut channels of overflow when the lake evaporated to a horizon below the rim of unconsolidated material that surrounded them; but the crater walls are now continuous and unbroken by stream channels. On the other hand, had the springs become extinct before the evaporation of the lake, the cavities they formerly occupied would be buried beneath lake beds. This, as our observations show, is not the case, but both the inner and outer surfaces of the cones are free from lake sediments. The latest additions to the cones must have been of post-Lahontan date. * * * There are no streams either tributary to or draining these lakes; their total water-supply, excepting the small amount derived from direct precipitation, is derived from subterranean sources. Around the immediate shores of the larger lake there are a number of fresh-water springs; the largest of these is situated on the northern border of the basin and issues from a small fault at an elevation of about 15 feet above the water surface. As the lake is 50 feet below the level of the Carson River at its nearest point, we may safely look to this stream as the probable source of the water-supply, which reaches the craters by percolation through the intervening marls and lapilli deposits. The bottom of the lake is a continuation of the slope of the inner walls of the crater, * * * is a fine black tenacious mud, having a strong odor of sulphuretted hydrogen. When exposed to the air for some time this material loses its inky color, and shows itself to be of the same nature as the fine dust-like lapilli that form a large part of the crater walls. The organic matter impregnating these sediments is evidently derived from the millions of brine shrimps (*Artemia gracilis*) and the larvæ of black flies that swarm in the dense alkaline waters.

My own observations in the summer of 1887 were confined to the technical aspects of the manufacture of sodium carbonate as carried on there, and the short time at my disposal did not allow me to take more than a cursory view of the formation, but I have little doubt that Mr. Russell's conclusions are correct, since they are supported by what may be seen at both Mono and Owen's Lakes.

The details of the manufacture of soda at these lakes are of great interest, since, as they differ so greatly in composition, an entirely different method must be employed for each.

The water of the larger lake collected in 1867 was analyzed by O. D. Allen (King's Rep., vol. 2, p. 747), and two samples, collected in 1882 by Mr. Russell in the central portion of the lake at the respective depths of 1 foot and 100 feet, were examined by me. My results, given below,

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agree very well, but differ from those of Allen mainly in that he reports the existence of sulphides, while I was unable to find any. If, as is very probable, Allen's sample was shipped to him in a keg, the presence of sulphides is easily accounted for by the reduction of sulphates by the action of the wooden vessel, since every sample of alkali water sent to this office in kegs has shown decomposition with resulting sulphuretted hydrogen, while the same material shipped in glass, as were Mr. Russell's waters, was free from it.

The variations in composition between the water at 1 foot and that at 100 feet may in part be due to the fact that the mother liquors of the soda works are run back into the lake. These mother liquors are poorer in carbonate and richer in chloride than the original water, and may in the course of years have changed the composition of the upper part of the lake.

The results are stated in grams per liter,[1] and the hypothetical combinations between the constituents are such as they may reasonably be expected to form. The columns of percentages show the relation of the constituents to each other, and will be found of practical value.

| Specific gravity at 19.8° C. | No. 1 (1 foot). 1.0995. | | No. 2 (100 feet). 1.0983. | |
|---|---|---|---|---|
| | Weight. | Per cent. | Weight. | Per cent. |
| Silica, $SiO_2$ | .304 | .24 | .310 | .25 |
| Magnesium, Mg | .270 | .21 | .270 | .21 |
| Potassium, K | 2.520 | 1.95 | 2.670 | 2.13 |
| Sodium, Na | 45.840 | 35.53 | 44.270 | 35.23 |
| Boric acid, $B_4O_7$ | .314 | .24 | .327 | .26 |
| Chlorine, Cl | 45.690 | 35.41 | 44.270 | 35.23 |
| Sulphuric acid, $SO_3$ | 10.800 | 8.37 | 10.593 | 8.43 |
| Oxygen, O | 2.160 | 1.68 | 2.117 | 1.69 |
| Carbonic acid, $CO_2$ | 15.351 | 11.89 | 15.128 | 12.04 |
| Oxygen, O | 5.583 | 4.34 | 5.501 | 4.38 |
| Hydrogen (in bicarbonates) H | .179 | .14 | .188 | .15 |
| | 129.011 | 100.00 | 125.644 | 100.00 |

[1] The statement of results of analyses of such waters as so many grammes to the liter is preferable to the usual method of stating them as so many parts per thousand or per million. Any one handling such material necessarily measures his solutions by volume and his products by weight. The metrical system is used throughout as in every respect more practical for the manufacturer, being not only a decimal system, but also giving an instantaneous conversion from measure to weight, and vice versa, without the labor of calculation. As small variations are sometimes met with in the tables found in ordinary books, we give the following as the best for comparison:

A liter of pure water at 4°C = 1000 grammes = 1 kilo = 2.2046 lbs. = .264131 U. S. gallons, 1000 kilos = 1.1023 ton (2000 lbs.). 1 U. S. gallon = 3.786 liters.

1 meter = 39.3708 inches. 1000 liters = 1 cubic meter.

The specific gravity of a liquid is the weight of a liter in grams. Thus a liter of Ragtown water, specific gravity 1.0995, weighs 1099.5 grams and a cubic meter 1099.5 kilos.

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| Hypothetical combination. | No. 1. | | No. 2. | |
|---|---|---|---|---|
| | Weight. | Per cent. | Weight. | Per cent. |
| Silica, $SiO_2$ | .304 | .24 | .310 | .25 |
| Magnesium carbonate, $MgCO_3$ | .945 | .73 | .945 | .75 |
| Potassium chloride, KCl | 4.808 | 3.73 | 5.094 | 4.06 |
| Sodium chloride, NaCl | 71.521 | 55.44 | 68.957 | 54.88 |
| Sodium sulphate, $Na_2SO_4$ | 19.170 | 14.86 | 18.800 | 14.96 |
| Sodium, bi-borate (borax) $Na_2B_4O_7$ | .406 | .31 | .423 | .34 |
| Sodium carbonate, $Na_2CO_3$ | 16.868 | 13.08 | 15.484 | 12.32 |
| Sodium bicarbonate, $NaHCO_3$ | 14.989 | 11.61 | 15.631 | 12.44 |
| | 129.011 | 100.00 | 125.644 | 100.00 |

*The Ragtown Soda Works.*—Mr. Russell's monograph contains an excellent map of the two lakes, drawn on so large a scale that the evaporating vats and their arrangements are clearly shown. He also gives many details of the manufacturing processes employed.

Two sets of works were in operation at the "Big Lake" in 1887, one belonging to Griswold & Epperson, the other to Smith & Allen. Both works use the same process and the evaporating vats are alike. Owing to the narrowness of the beach it was necessary to build the vats in the water, which was done by running out levees at right angles to the shore and connecting the ends of these by a main dike, thus forming rectangular compartments, which by use gradually became practically water-tight. Along the shore back of the vats runs a ditch, which is kept filled with lake water, and from this the vats are filled as needed.

Certain of the vats are used as "crystallizers," the rest as "evaporators." At the beginning of the season all are filled with lake water, and as this concentrates it is drawn from the evaporators into the crystallizers, so as to keep the latter at the proper depth—about 12 to 15 inches. As fast as this is done the evaporators are filled up with lake water from the ditch. In concentrating the brine gradually becomes a deep red (see page 95) and when it reaches 30° Baumé crystallization usually begins. From this time on, the crystallizers must be carefully watched lest the soda as it forms should be too much contaminated with sulphate or chloride. There is no simple means of detecting the formation of sulphate, but when common salt forms it crystallizes in minute glistening cubes upon the surface of the brine. A sudden lowering of the temperature generally has this effect, which must be remedied by drawing off a part of the mother liquor and supplying its place with concentrated brine from the evaporaters or even with lake water. This drawing off is, of course, only necessary if the vat is already full, otherwise the concentrated brine or lake water is added directly to the vat in sufficient quantity to re-dissolve the NaCl.

The crystallization process is allowed to go on in this manner until the sheet of crystals at the bottom of the vat has grown thick enough



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to be easily gathered or "lifted," say one-half inch to 1½ inches. The mother liquor is then drawn off into the lake, and the crop lifted and stacked up to drain. As this soda is made during the summer it is known as "summer soda," and is the product of the Big Lake. This is the material called in King's report "trona," but is in reality "urao," as will be shown by the analysis on page 52. In the process of gathering the crystal sheet is broken up into cakes, which are a hard and compact aggregate of crystals sometimes well formed.

When the crop is drained it is heated in a furnace to remove the water of crystallization and the excess of carbonic acid, and is then sacked and shipped as "soda ash."

The furnace is a single hearth reverberatory, the hearth bed being made of iron plate. The fire gases pass over the charge to the end of the hearth, then through two side flues, one on each side, under the iron plate, back to the bridge wall, thence return through a center flue to the end of the hearth, where the stack is placed. The soda is dumped through an opening in the top of the arch onto the hearth, and is spread out evenly and heated for three hours, and then stirred from time to time until it is entirely dry. The furnacing as there practiced is a very simple operation, as the material parts with its water readily, and does not fuse, or even sinter, unless the heat is too high, and this is easily prevented by a little care in the stirring. In regular operation nine charges are worked off in a week; the fuel is sage-brush, gathered in the vicinity. Annual production about 450 tons, but this could easily be made much larger.

The operations at the Little Lake are conducted on an entirely different principle. The lake, as described in King's report, no longer exists, but the present appearance of the place is well shown in Russell's map. In the center of the depression there were at the time of my visit (1887) four large but shallow pits, besides a shallow pool somewhat larger, and filled with fresh water from the small springs which issue from the sides of the crater. Two of the pits are used as crystallizers and are supplied from the others, which contain a lye of about 12° to 13° Baumé. The lye is formed by the gradual solution of the "ledge" or deposit of crystallized sodium carbonate which exists in the bottom. No analysis of this ledge has so far as is known ever been made, and in consequence of the work which has been done it is difficult to obtain specimens. That material which was dug out for me had a close resemblance to dirty ice, although at one time it could be obtained in masses of considerable size and quite clean. Its appearance and the nature of its solution leave no doubt that it is a natural "crystal soda" or $Na_2CO_3$ $10H_2O$ in a comparatively pure condition.

The solution of this deposit, owing to the small amount of bicarbonate present, yields but little "summer soda." The concentration therefore continues, more lye being added from time to time until cold weather

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sets in. Usually by January the lye is sufficiently concentrated and chilled, resulting in a copious crystallization of "winter soda" or $Na_2CO_3$, $10H_2O$, which is deposited on the thin layer of summer soda on the bottom of the vat.

When no more crystals appear to form, by which time the deposit is 10 or 12 inches thick, the crop is lifted and carefully stacked preparatory to the drying process, the most delicate part of the work. The $10H_2O$ salt contains 63 per cent. of water, and parts with most of it with great ease and rapidity, so that if heated to 33°C. (90°F.) it melts in its own water of crystallization and becomes a liquid. In drying the crop great care must therefore be exercised lest the material should become liquid and much of it be lost.

The crop is therefore kept in the stacks until the approach of warm weather, when it is broken up and spread in a layer two or three inches deep on the drying floors, which are covered with light sheds open at the sides. The material is turned over from time to time and the lumps broken up. When the drying is completed the product is a thoroughly effloresced white powder, in which the summer soda appears as small pieces of thin cakes. The annual product amounts to about 300 tons.

Before giving the analyses of the products of the two lakes, a few words of comparison between these two processes will aid much in giving a clear understanding of the meaning conveyed by the analytical figures.

The analysis of the water of the Big Lake has already been given. Though no analysis of the deposit of the Little Lake can be furnished, it is evident that it must give a solution much poorer in chloride and sulphate than the first locality. Let us see why this must be so.

When Hague visited these lakes in 1868 they had never been worked, and were therefore in their original condition. From the Little Lake he collected the material of which the analysis is given on page 46. On the shore of the Big Lake there were "large fields of dazzling white carbonate of soda," a sample of which was examined by O. D. Allen with the following results:

| | |
|---|---|
| Water, $H_2O$ | 19.90 |
| Insoluble residue | .80 |
| Sulphuric acid, $SO_3$ | .73 |
| Chlorine, Cl | .98 |
| Carbonic Acid, $CO_2$ | 36.86 |
| Soda, $Na_2O$ | 40.55 |
| | 99.82 |
| Deduct oxygen = Cl | .22 |
| | 99.60 |

The deduction of oxygen=Cl is made because the whole of the Na is calculated as oxide $Na_2O$, whereas that part combined with Cl is present as Na.

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To compare these two analyses, let us calculate the hypothetical combination of this last analysis and place it side by side with the first one, in which the 28.83 per cent. of $CO_2$ and $H_2O$ have been divided into the constituents, so that the full theoretical amount of $Na_2CO_3$ is supposed to be present. If the theoretical amount of $NaHCO_3$ be taken, the results will be found to vary very slightly.

| | Big Lake. | Little Lake. |
|---|---|---|
| Insoluble matter | .80 | 2.81 |
| Sodium sulphate, $Na_2SO_4$ | 1.29 | .99 |
| Sodium chloride, NaCl | 1.61 | 1.10 |
| Sodium carbonate, $Na_2CO_3$ | 45.05 | 44.25 |
| Sodium bicarbonate, $NaHCO_3$ | 34.66 | 34.90 |
| Water, $H_2O$ | 16.19 | 15.95 |
| | 99.60 | 100.00 |

If we were to deduct the insoluble matter from each of these analyses and recalculate them we should find but little difference between the two samples, which will be referred to later in the section treating of urao. They evidently represent the first and purest crystallization of the "summer soda" from the two lakes.

At the Big Lake, however, the process must stop at the point where this crystallization is obtained, while at the Little Lake the process is allowed to go on and the "winter soda" is collected with the summer product. Russell procured samples of the "market soda" from each of these lakes, but neither of them seems to have been correctly taken, as the Little Lake soda contains too large a proportion of summer soda and the Big Lake material is the result of attempts, which naturally failed, to make winter soda at that place.

| | Big Lake. | Little Lake. |
|---|---|---|
| | F. W. Taylor. | Chatard. |
| Silica, $SiO_2$ | .449 | .27 |
| Iron and alumina, $Fe_2O_3, Al_2O_3$ | .011 | ..... |
| Calcium sulphate, $CaSO_4$ | .038 | ..... |
| Magnesium sulphate, $CaSO_4$ | .040 | ..... |
| Sodium chloride, NaCl | 2.193 | 3.31 |
| Sodium sulphate, $Na_2SO_4$ | 49.437 | 5.10 |
| Sodium carbonate, $Na_2CO_3$ | 40.714 | 52.20 |
| Sodium bicarbonate, $NaHCO_3$ | ..... | 25.05 |
| Water, $H_2O$ | 7.118 | 14.16 |
| | 100.000 | 100.09 |

These two analyses are valuable for comparison in this connection, although in the first one the acid $CO_2$ of the $NaHCO_3$ was not determined,

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being included in the $H_2O$ which was evidently determined by difference. The chilling of the solutions would not materially increase the deposition of NaCl, but would greatly increase that of $Na_2SO_4$, hence the solution of the Little Lake must contain much less of the latter salt than the other water, the analysis of which has been given.

The combined product of the two lakes, as has been stated, is about 750 tons per annum. The Little Lake has nearly reached the limit of its annual capacity, but the Big Lake might without great expense yield far more. With proper working the two lakes should yield 1,500 tons per annum.

*Mono Lake, Mono County, Cal.*—A very extensive description of this locality is given by Mr. I. C. Russell in his article "Quaternary History of Mono Valley," in the Eighth Annual Report of the U. S. Geological Survey, and I can only repeat what I have elsewhere said "that this large body of water, of a composition so favorable to utilization, is, for practical purposes, inaccessible and that the high altitude and consequent shortness of the evaporating season would, under any circumstances, render the success of any industry established there very doubtful.[1] The composition of the water is, as shown by the annexed analysis, very similar to that of Owen's Lake, which will be considered directly, and the same methods of economic treatment would apply to both, but owing to the reasons given above, there is little prospect that any extended use of the water of Mono Lake can ever be made.

The sample analyzed was collected by Mr. Russell in 1882 and was taken at the depth of one foot, on east side of lake.

Specific gravity, 1.045 at 15.5°.

| | In 1 liter. | Per cent. | Hypothetical composition. | | Per cent. |
|---|---|---|---|---|---|
| $SiO_2$ | .0700 | .12 | $SiO_2$ | .0700 | .13 |
| K | .9614 | 1.79 | $(Al_2Fe_2)O_3$ | .0030 | .005 |
| Na | 19.6853 | 36.81 | $CaCO_3$ | .0500 | .09 |
| Ca | .0200 | .037 | $MgCO_3$ | .1928 | .36 |
| Mg | .0551 | .10 | $Na_4B_4O_7$ | .2071 | .39 |
| $(Al_2Fe_2)O_3$ | .0030 | .005 | KCl | 1.8365 | 3.44 |
| $SO_4$ | 6.6720 | 12.480 | NaCl | 18.5033 | 34.60 |
| $CO_3$ | 13.6903 | 25.61 | $Na_2SO_4$ | 9.8690 | 18.45 |
| $B_4O_7$ | .1600 | .30 | $Na_2CO_3$ | 18.3556 | 34.33 |
| Cl | 12.1036 | 22.64 | $NaHCO_3$ | 4.3856 | 8.20 |
| H | .0522 | .10 | | | |
| | 53.4729 | 100.00 | | 53.4729 | 100.00 |

*Abert Lake, Oregon.*—This lake, situated in southeastern Oregon, may in time become of considerable importance, for though at present far distant from railroads and hence unavailable, yet with proper transpor-

[1] Chatard, Am. Jour. Sci., ser. 3, vol. 36, p. 148.

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tation facilities the water could be utilized. The subjoined analysis of the water shows it to be the best suited for solar evaporation of all the lakes of the Great Basin, since, though not as concentrated as some others, the relation of the constituent salts is such that simple evaporation should give a very pure product. Summer Lake, not far distant, is supposed to have a similar composition.

Both lakes have been described by I. C. Russell[1] and by H. T. Biddle.[2] Mr. Russell's paper contains the following analysis of the waters of Abert Lake, which shows a very large percentage of potash (loc. cit. p. 454).

| Sp. G., 1.02317. | Grams in liter. | Sp. G., 1.02317. | Grams in liter. |
|---|---|---|---|
| Silica in solution.. | 0.065 | $K_2CO_3$ ..... | 10.961 |
| NaCl..... | 7.219 | $MgCO_3$ ..... | .006 |
| KCl..... | 8.455 | | 27.357 |
| $K_2SO_4$ ..... | 9.921 | | |

From what is known of geological chemistry and the phenomena of rock decomposition, it is safe to say that no lake of this composition, or containing such a large proportion of potash, could be formed, but if such an occurrence should ever be discovered, the rock decompositions yielding such a solution must necessarily be entirely different from all those so far observed. It is due to my friend Dr. Taylor, who made the analysis in 1882, to state that when, some years later, his attention was called to this matter he at once recognized the unlikelihood of such a composition, but as the balance of his sample had not been preserved and he was unable to find the figures of his analyses, he could not rectify the error, which is probably only a simple arithmetical error of calculation in the estimation of the alkalies.

Mr. Biddle collected and examined a sample of the water of Abert Lake, and being unable to verify Dr. Taylor's results sent me the residue of his sample, which was examined with great care to settle the doubt. The sample was "collected by H. T. Biddle at middle of west side of lake, one foot below surface, 30–40 feet from shore, September, 1887." The total quantity at my disposal was about 200cm.$^3$, an amount too small for any extended research, but sufficient for all practical purposes. For each determination, 25cm.$^3$ = 25.7792 grams were taken.

Specific gravity, 1.03117 at 19.8°.

[1] Russell: Geological Reconnaissance in Southern Oregon, Fourth Annual Report U. S. Geological Survey, p. 435 et seq.

[2] Biddle, H. T.: Am. Jour. Sci., 3d ser. vol. 35, p. 475.

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| | Contents in 25 cm³. | | | In 1 liter. | Per cent. | | Hypothetical composition. | Per cent. |
|---|---|---|---|---|---|---|---|---|
| | A. | B. | Average. | | | | | |
| $SiO_2$ | .0063 | .0053 | .00580 | .232 | .59 | $SiO_2$ | .232 | .59 |
| K | .0133 | .0136 | .01345 | .538 | 1.37 | KCl | 1.027 | 2.62 |
| Na | .3674 | .3671 | .36725 | 14.690 | 37.51 | NaCl | 21.380 | 54.58 |
| $SO_3$ | .0148 | .0146 | .01470 | .588 | 1.50 | $Na_2SO_4$ | 1.050 | 2.68 |
| O | .0030 | .0029 | .00295 | .118 | .30 | $Na_2CO_3$ | 10.611 | 27.09 |
| $CO_2$ | .1755 | .1757 | .17560 | 7.024 | 17.93 | $NaHCO_3$ | 4.872 | 12.44 |
| O | .0615 | .0616 | .06155 | 2.462 | 6.28 | | | |
| Cl | .3365 | .3366 | .33655 | 13.462 | 34.67 | | | |
| H in bicarbonates | ..... | ..... | ..... | .058 | .15 | | | |
| | ..... | ..... | ..... | 39.172 | 100.00 | | 39.172 | 100.00 |

This analysis shows, as would be expected, that the water of Abert Lake does not differ materially from that of any other alkali lake so far discovered. Its low percentage of sulphate is its greatest merit, since, as will be shown under the section treating of Owen's Lake, it is of all the impurities the most difficult to remove and the most deleterious when present.

*Dry deposits in the United States.*—With the exception of Owen's Lake, the foregoing are the only lakes which have a prospective value for the alkali industry, although there are many others which are alkaline, but are too dilute for profitable working. There is, however, another class of alkali occurrences which may in time become available, though at present of minor importance. These are the so-called dry deposits left by the desiccation of shallow lakes formed in the wet season by the drainage of the surrounding country, but drying up more or less completely during the summer, leaving an incrustation of salts often of considerable extent, though usually of no great thickness.

In the region of the Black Rock Desert and adjacent parts lying between Abert Lake and the line of the Central Pacific Railway there are many places which furnish such salts. The following analyses will give an idea of their composition:

No. 1. Soluble portion of incrustation from near Black Rock Point, Black Rock Desert. Chatard. I. Russell, Monograph XI, U. S. Geological Survey, p. 231.
No. 2. Quinn's River salts. O. D. Allen. King, 40th Parallel Survey, vol. 2, p. 791.
No. 3. Hardin City salts, O. D. Allen. King, ibid., p. 792.

| | No. 1. | No. 2. | No. 3. |
|---|---|---|---|
| $SiO_2$ | 2.18 | *1.82 | ..... |
| KCl | 1.39 | †8.57 | ..... |
| NaCl | 59.32 | 85.27 | 18.47 |
| $Na_2B_4O_7$ (borax) | 1.00 | ..... | ..... |
| $Na_2SO_4$ | 27.05 | 1.75 | 27.55 |
| $Na_2CO_3$ | 9.06 | 2.59 | 52.10 |
| | 100.00 | 100.00 | 98.12 |

*Residue. †Water.

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The next five are also from King's 40th Parallel Exploration, and show the general character of the alkaline incrustations of eastern and central Nevada. In each case the amount of $H_2O$ necessary to form $NaHCO_3$ has been added and the analysis calculated to 100 per cent. for comparison.

No. 4. Ruby Valley, Nevada (Woodward), vol. 1, p. 503.
No. 5. Valley of Deep Creek, Utah (Woodward), vol. 2, p. 474.
No. 6. Antelope Valley, Nevada (Woodward), vol. 2, p. 541.
No. 7. Humboldt Valley, Nevada (Woodward), vol. 2, p. 594.
No. 8. Brown Station, Humboldt Lake (Woodward), vol. 2, p. 744.

| | No. 4. | No. 5. | No. 6. | No. 7. | No. 8. |
|---|---|---|---|---|---|
| $K_2SO_4$ | 2.79 | 4.68 | 1.88 | ..... | ..... |
| $Na_2SO_4$ | 28.32 | 17.43 | 33.31 | 4.42 | 49.67 |
| NaCl | 2.11 | 38.01 | 24.51 | 7.24 | 20.88 |
| $Na_2CO_3$ | 58.69 | 25.12 | 25.95 | 48.99 | 7.02 |
| $NaHCO_3$ | 8.09 | 14.76 | 14.35 | 36.01 | 11.13 |
| $Na_2B_4O_7$ | ..... | ..... | ..... | 3.34 | 11.30 |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

At many localities in western Nevada and in that portion of California east of the Sierra, incrustations of like character occur. Of these perhaps the most important are the soda lakes in Long Valley, California, lying southeastwardly of Mono Lake. The country is highly volcanic and the rocks are in many places much decomposed, having upon them efflorescences and incrustations. There are many warm springs, the waters of which flow into the lakes. These are several in number, connected together, with a drainage during the wet season into the headwaters of Owen's River. The shore shows in most places a salt crust around the margin, but in the hurried visit I paid this locality in the summer of 1886, I had no time to make a more particular examination, especially as the lakes are the deepest portions of extensive morasses, which in the winter are completely flooded. In the vicinity are large stretches of playa covered with thin sheets of alkaline salts, which are said to grow to the thickness of two or three inches on the approach of cold weather, when the material is gathered for the use of the mills at Bodie. A little to the north of the lakes is a so-called "hopper," a depression in the plain resembling on a small scale the Little Lake at Ragtown. The deepest part is filled with a small pool on which is a salt crust which covers the remainder of the bottom. The alkali from this place is also collected. Were there any facilities for transportation Long Valley might be made to yield a considerable amount of soda annually.

There are many other localities in this region, but further enumeration would be useless as the entire country is volcanic in its character,

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and so far as there is any drainage the water flows into Owen's Lake.

*Owen's Lake.*—By far the most important natural source of soda is Owen's Lake, Inyo County, California, both on account of its magnitude and of the facilities for carrying on extensive operations.

It was visited by a party of the Wheeler Survey in 1875, and is described in the reports of Lieutenant Birnie and Dr. Oscar Loew, published in "Report of U. S. Geographical Surveys west of the 100th Meridian, 1876," pp. 130–135 and 189–190. Both in the summer of 1886 and of 1887 I spent some time at the lake, and as the Inyo Development Company has begun the manufacture of soda at Keeler, a small village on the shore of the lake at the terminus of the Carson and Colorado Railroad, every needed facility for observation and experiment was most courteously extended.

Loew (loc. cit.) states that the greatest length of the lake is 17 miles, its greatest width 9 miles, and greatest depth 51 feet. The total surface is given by him as nearly 110 square miles, and from his analysis of the water he calculates the total contents of the lake in sodium carbonate as 22,000,000 tons, and suggests the utilization of this great chemical treasure.

The lake lies between the Sierra Nevada on the west and the Inyo range on the east and has no outlet, the lowest point of the rim of the valley to the southward being, as I am informed, about 50 feet higher than the present level of the lake. On the western side several small streams from the Sierra make their way to the lake, but the greater portion of the water supply is furnished by the Owen's River which empties into the lake at its northern end. This, according to Loew, is a stream about 30 feet wide, 2 feet deep, with a velocity of about 5 miles an hour. It was my intention to collect accurate data concerning this river, as well as to get samples of the water taken at different points so as to determine the origin of the carbonate in the lake, but circumstances have prevented the prosecution of this part of the investigation.

As would be naturally expected the lake is somewhat higher in the spring than in the autumn, but its average depth suffers but little change, hence the evaporation from its surface seems to be at present about equal to the amount of water received from all sources. As the valley lies between two high ranges of mountains, and is open to the north and south, there is usually a good breeze through the greater part of the twenty-four hours, thus much increasing the evaporation which may safely be taken as about 5 feet in the year, though experiments give a larger result.

On the eastern side, the valley slopes gradually from the foot-hills to the lake. The shore is covered in most places with a strong growth of salt grass, though there are extensive sandy flats which are bare.

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In the lake itself are large quantities of a sort of "algous or fungoid plant, floating in small globular masses of a whitish or yellowish green" (Loew). This collects in patches upon the water and becomes black with the clouds of "alkali flies" or ephydra which settle on it. In addition to the larva of these flies the water swarms with the artemia.

A carefully selected sample of the water of this lake taken September 17, 1886, gave me the following results. All the determinations were made in duplicate, the duplicates agreeing very closely. Specific gravity, 1.062 at 25°.

| | In 1 liter. | Per cent. | | Hypothetical composition. | Per cent. |
|---|---|---|---|---|---|
| $SiO_2$ | .220 | .28 | $SiO_2$ | .220 | .28 |
| K | 1.644 | 2.13 | $(Al_2Fe_2)O_3$ | .038 | .13 |
| Na | 28.500 | 36.96 | $(CaMg)Co_3$ | .055 | |
| Ca | .014 | .02 | $Na_2B_4O_7$ | .475 | .63 |
| Mg | .005 | ..... | KCl | 3.137 | 4.07 |
| $Fe_2O_3$ | .014 | .02 | NaCl | 29.415 | 38.16 |
| $Al_2O_3$ | .024 | .03 | $Na_2SO_4$ | 11.080 | 14.38 |
| $SO_4$ | 7.505 | 9.73 | $Na_2CO_3$ | 26.963 | 34.95 |
| $B_4O_7$ | .367 | .49 | $NaHCO_3$ | 5.715 | 7.40 |
| $CO_3$ | 19.398 | 25.16 | | | |
| Cl | 19.344 | 25.09 | | | |
| H | .063 | .10 | | | |
| | 77.098 | 100.00 | | 77.098 | 100.00 |

*Owen's Lake Soda Works.*—The works of the Inyo Development Company begun in the winter of 1885–'86, had so far progressed by the summer that a small amount of crude soda was produced. Lack of experience on the part of those in charge caused, however, many delays and disappointments, and it was not until the summer of 1887 that, under the management of Mr. Frank Gray, formerly of Ragtown, a fair start was made.

There are now nearly 15 acres of vats, mostly well made. The slope of the ground is such that the vats can be, in general, arranged in two lines so that the upper ones can be used as evaporators, the lower as crystallizers. By the method introduced by Mr. Gray the lye is allowed to concentrate in the crystallizers, more concentrated solution from the evaporators being added from time to time, till a sufficient quantity of the first crop is formed. This first crop is, however, comparatively soft and mushy owing to the small size of the crystals, so the mother liquor is drawn off; clear, well-settled lake water is added in sufficient quantity to redissolve the crystals and when this is done as completely as practicable, the vat is then filled up from the evaporators. By this means a new solution is obtained, containing a much smaller

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proportion of chlorides and sulphates than the original lake water, and the crystals obtained from it are much larger and purer. The crystallization is allowed to go on, with additions from the evaporators until the cooler weather begins, when the soda is lifted.

The cake is then two or more inches in thickness, and if proper care be taken during its formation it should be quite clean and contain but little sulphate or chloride. An analysis of a sample of the crop of 1887, a good specimen but not better than could be made on a large scale with experience and judicious management, is given on page 76; "best specimen," while the "crude" is the undissolved first crop.

The process of furnacing this material so as to convert it into soda ash is very simple and easy, since the water and acid $CO_2$ is driven out at a temperature but little above 150° C. (300° F.), and no fusion takes place. If the material represented by the "best specimen" be thus heated it would give an ash containing 97.77 per cent. $Na_2CO_3$, while the "crude" treated in the same manner would yield a 94 per cent. ash. When we consider that these favorable results have been obtained in the infancy of a process, without special skill or experience, it is not unreasonable to expect that, under proper technical management and with suitable arrangements and appliances, a product averaging 98 per cent. $Na_2CO_3$ can be made regularly and in large quantities, at this locality.

The calculation of Loew shows that this lake contains 22,000,000 tons of $Na_2CO_3$, and if we make the moderate estimate that one-half of this amount can be extracted from it, and consider the natural advantages of climate and of the character of the shore which in many places is well adapted for the location of extensive works, there seems to be no reason why, in time, a large and flourishing industry should not develop there.

The small amount of the annual rain-fall and the very great annual evaporation resulting from a long season of very warm and dry weather, are extremely favorable. No experiments determining the annual excess of evaporation over precipitation, have been made in this region, but we have reason to think that it is not less than 7 feet per annum. The experiments now to be detailed show a much greater rate, but as they were carried on in small vessels fully exposed to the rays of the sun, the daily loss is, of course, far larger than would occur when an earth vat of large size is used for the purpose.

## EXPERIMENTS ON THE EVAPORATION AND FRACTIONAL CRYSTALLIZATION OF THE WATER OF OWEN'S LAKE.

These investigations were made during the summer of 1886, for the purpose of obtaining information needed for the devising of manufacturing methods suitable for such waters.

*Evaporation.*—On September 6, noon, a granite-ware pot 7½ inches

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interior diameter, 6 inches deep, with straight sides, was filled $5\frac{3}{4}$ inches deep with lake water, specific gravity 1.057 at 18.3° (65° F.) The pot then contained $8\frac{1}{2}$ pints, the measurement of depth being made by sliding a rule along the side of the vessel until the lower end of the rule just touched the water. By having a thin strip of metal bent over the edge of the vessel the measurements can be made very closely. By using short hydrometers the specific gravity of the solution could be readily taken without disturbing the liquid.

| Date. | Hour. | Depth to surface. | Loss. | Specific gravity. | Temperature. | Remarks. |
|---|---|---|---|---|---|---|
| | | *Inches.* | *Inches.* | | | |
| Sept. 6 | 12 m ..... | $\frac{1}{4}$ | ..... | 1.057 | 65° F. 18.3° C. | Filled pot; water filtered and clear. |
| Sept. 7 | 7.30 a. m. | $\frac{7}{8}$ | $\frac{5}{8}$ | 1.07 | 60° 15.5° | |
| Sept. 7 | 5.30 p. m. | $1\frac{1}{4}$ | $\frac{3}{8}$ | ..... | | |
| Sept. 8 | 8.40 a. m. | $1\frac{5}{8}$ | $\frac{3}{8}$ | 1.077 | 71° 21.7° | |
| Sept. 8 | 4.35 p. m. | 2 | $\frac{3}{8}$ | 1.082 | 82° 27.8° | |
| Sept. 9 | 7.45 a. m. | $2\frac{1}{4}$ | $\frac{1}{4}$ | 1.090 | 75.5° 24° | |
| Sept. 9 | 4.15 p. m. | $2\frac{1}{2}$ | $\frac{1}{4}$ | 1.093 | 85° 29.4° | |
| Sept. 10 | 8.25 a. m | $2\frac{3}{4}$ | $\frac{1}{4}$ | 1.103 | 71° 21.7° | Slightly whitish deposit at edge of liquid. Liquid slightly turbid. |
| Sept. 10 | 5.15 p. m. | 3 | $\frac{1}{4}$ | 1.110 | 85° 29.4° | |
| Sept. 11 | 7.50 a. m. | $3\frac{3}{16}$ | $\frac{3}{16}$ | 1.120 | 67.5° 15.8° | A minute surface crystallization observed, probably $CaCO_3$. Liquid more turbid. |
| Sept. 11 | 5.15 p. m. | $3\frac{1}{2}$ | $\frac{5}{16}$ | 1.127 | 84° 28.9° | Hot wind from south. |
| Sept. 12 | 8.30 a. m. | $3\frac{5}{8}$ | $\frac{1}{8}$ | 1.138 | 74° 23.3° | Liquid quite turbid. A thin granular precipitate on bottom and sides of vessel. |

The concentrated solution was at this time transferred to a smaller granite-ware pot $6\frac{1}{2}$ inches wide, $5\frac{1}{2}$ inches deep. The surface of the solution was $2\frac{1}{4}$ inches below edge of pot, and, as the capacity of the vessel had been carefully measured for successive depths, the volume of the solution was $3\frac{1}{2}$ pints. The granular precipitate which adhered to the large pot consisted of $CaCO_3$ with a little $Fe_2O_3$.

As the original solution measured $8\frac{1}{2}$ pints there was a loss of 5 pints, or 58.82 per cent., in bringing it to 1.138 (18° B.) at 23.3° (74° F.). When the liquid reaches 1.096 (13° B.) it begins to deposit its $CaCO_3$, the maximum of deposit being at about 1.130–1.138 (17°–18° B.). No increase of deposit was observed after the latter point was reached.

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| Date. | Hour. | Depth. | Loss. | Specific gravity. | Temperature. | Remarks. |
|---|---|---|---|---|---|---|
| | | *Inches.* | *Inches.* | | | |
| Sept. 12 | 4.45 p. m. | $2\frac{8}{16}$ | $\frac{1}{16}$ | 1.150 | $\frac{89°}{31.67°}$ | |
| Sept. 13 | 7.35 a. m. | $2\frac{3}{4}$ | $\frac{2}{16}$ | 1.165 | $\frac{64°}{17.78°}$ | |
| Sept. 13 | 4.45 p. m. | 3 | $\frac{4}{16}$ | 1.175 | $\frac{84.5°}{29.1°}$ | |
| Sept. 14 | 8.20 a. m. | $3\frac{1}{4}$ | $\frac{4}{16}$ | 1.190 | $\frac{72°}{22.2°}$ | |
| Sept. 14 | 5.00 p. m. | $3\frac{1}{2}$ | $\frac{4}{16}$ | 1.215 | $\frac{85°}{29.44°}$ | |
| Sept. 15 | 9.00 a. m. | $3\frac{13}{16}$ | $\frac{5}{16}$ | 1.232 | $\frac{75°}{24°}$ | |
| Sept. 15 | 4.30 p. m. | $3\frac{3}{4}$ | $\frac{4}{16}$ | 1.250 | $\frac{87.5°}{23.9°}$ | |
| Sept. 16 | 8.45 a. m. | $3\frac{7}{8}$ | $\frac{3}{16}$ | 1.260 | $\frac{77°}{25°}$ | Incipient crystallization. |
| Sept. 16 | 4.35 p. m. | 4 | $\frac{3}{16}$ | 1.273 | $\frac{100°}{37.78°}$ | Crust formed. |

At 8.45 a. m., the solution measured $1\frac{3}{8}$ pints. Hence during the concentration to the crystallizing point the liquid lost $6\frac{5}{8}$ pints, or 80.4 per cent. of its bulk, or 5 volumes of Owen's Lake water at the specific gravity and temperature above given are reduced to one volume when crystallization begins. From these figures the proper relation between the evaporating and the crystallization surface is at once obtained. As should be expected the daily loss diminishes as the solution concentrates; the total time of evaporation was nearly ten days, the average loss one-half inch per diem, maximum loss one inch, minimum one-fourth inch. Observations on earth vats, although roughly made, indicate an average evaporation of one-fourth inch in twenty-four hours under the same circumstances.

The rapid heating of the solution as soon as a crystal crust had formed on the surface is also worthy of notice.

*Fractional crystallization.*—The following experiments were made in order to determine the character and composition of the successive crops of crystals obtained by the continued evaporation of a portion of Owen's Lake water, until the point is reached when the sun's heat is no longer sufficient to drive off the water except with great slowness; or, in other words, to observe the gradations and extent of a practical soda evaporation.

September 3, 11.30 a. m.—Five quarts of filtered, partly concentrated lake water were put into each of two granite-ware pans, which were then placed in the sun. The water had a specific gravity of 1.135 at $\frac{80°}{26.67°}$, the 10 quarts, so taken, being equivalent to 25 quarts of original water.

September 5, 8.30 a. m.—The solution in each pan had deposited a small quantity of a fine granular precipitate, while a few stout acicular

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crystals were floating on the surface. Solution pan No. 1, 1.282; No. 2, 1.270, both at $\frac{65^\circ}{13.36^\circ}$. Filled up pans with filtered water from vat, specific gravity 1.19 at $\frac{76^\circ}{24.4^\circ}$, adding to each 3 quarts, equivalent to 7½ quarts original water. The total amount in the two pans was therefore equivalent to 40 quarts of lake water.

September 6, 7.30 a. m.—Both pans showed a large crop of crystals on bottom, while the liquid was turbid, with small crystals floating in it. Specific gravity of both solutions, 1.250 at $\frac{60^\circ}{15.5^\circ}$.

September 7.—Both pans had a stout crust with large deposit.

3.45 p. m.—Poured off mother liquor from both pans and drained crystals. The crop A1 weighed 1½ pounds when dry. The combined mother liquors measured 5½ quarts and had a specific gravity of 1.312 at $\frac{80.5^\circ}{27.9^\circ}$. This was put in one of the pans and allowed to evaporate.

September 8.—The solution was covered by a thin crust, with a considerable deposit of minute crystals on bottom.

September 9.—Poured off mother liquor from second crop, A2, which weighed 1 pound, and drained the crystals thoroughly. Mother liquor 1.312 at $\frac{77^\circ}{25^\circ}$.

September 10, 8.30 a. m.—Pan showed a considerable deposit of fine granular salts with thin crust on surface.

September 11, 8.30 a. m.—Drew off mother liquor and secured third crop, A3., which was highly saline to taste, and weighed three-fourths of a pound. The mother liquor had a specific gravity of 1.315 at $\frac{79.25^\circ}{26.25^\circ}$.

September 12, 5 p. m.—The solution was covered with thin, floating crusts, and its temperature was $\frac{103^\circ}{39.44^\circ}$, while the same thermometer exposed for five minutes to the direct rays of the sun showed barely $\frac{90^\circ}{32.2^\circ}$; another solution; B, of about 1.29 showed $\frac{91^\circ}{32.78^\circ}$.

The evaporation of this concentrated solution was very slow, so it was undisturbed until the 18th, when, as no further reduction in volume could be observed, the mother liquor was poured off, leaving the fourth crop A4. It had a specific gravity of 1.327 at $\frac{96.6}{35.75^\circ}$.

To observe the effect of cold at this stage, the vessel containing the solution was surrounded with ice. After four hours, at a temperature of $\frac{45^\circ}{7.22^\circ}$ a large deposit of a slushy material, looking like wet snow, was obtained. This crop, A5, was collected and placed in a pan to dry, but speedily melted in its water of crystallization, afterwards becoming a dry cake on the bottom of the pan. The mother liquor had a specific gravity of 1.300 at $\frac{57^\circ}{13.89^\circ}$, and was preserved for analysis.

The salts so obtained were analyzed with the following results, to which is prefixed an analysis of a sample of the crude soda made at the works in that year:

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| | Crop 1886. | A1. | A2. | A3. | A4. | A5. |
|---|---|---|---|---|---|---|
| Sp. gr. mother liquor | 1.280 (80° F.) | 1.312 (80.5°) | 1.312 (77°) | 1.315 (79.25°) | 1.327 (96.6°) | 1.300 (57°) |
| Water at 120° C., $H_2O$ | 23.82 | 17.10 | 5.04 | 3.57 | 2.37 | 10.53 |
| Water at red heat, $H_2O$ | .33 | .54 | .41 | .29 | .24 | .92 |
| Insoluble matter | 1.55 | .078 | ..... | ..... | ..... | ..... |
| Organic matter | .18 | .032 | ..... | ..... | ..... | *1.14 |
| Silica, $SiO_2$ | .14 | .055 | .055 | .27 | .05 | .16 |
| Alumina, $Al_2O_3$ | .01 | .01 | .015 | .03 | .01 | .02 |
| Lime, CaO | .01 | .07 | .02 | ..... | ..... | ..... |
| Magnesia, MgO | .01 | .01 | .009 | .009 | ..... | ..... |
| Sulphuric acid, $SO_3$ | 1.07 | 1.795 | 14.33 | 15.05 | 10.70 | 3.22 |
| Chlorine, Cl | 2.36 | 4.84 | 21.81 | 28.81 | 37.59 | 13.01 |
| Carbonic acid, $CO_2$ | 33.04 | 33.98 | 15.00 | 9.67 | 7.25 | 24.93 |
| Soda, $Na_2O$ | 37.91 | 41.87 | 46.93 | 48.47 | 48.69 | 47.29 |
| Potash, $K_2O$ | .32 | .68 | .71 | .72 | .76 | 1.85 |
| | 100.75 | 101.15 | 104.33 | 106.64 | 108.66 | 103.07 |
| Deduct O=Cl | .53 | .78 | 4.91 | 6.49 | 8.75 | 2.93 |
| | 100.22 | 100.37 | 99.42 | 100.15 | 99.91 | 100.14 |

* Boric acid, $B_2O_3$.

*Hypothetical combination.*

| | Crop 1886. | A1. | A2. | A3. | A4. | A5. |
|---|---|---|---|---|---|---|
| $H_2O$ | 20.87 | 14.51 | 4.33 | 3.43 | 2.24 | 11.03 |
| Insoluble | 1.55 | .078 | ..... | ..... | ..... | ..... |
| Organic | .18 | .032 | | | | |
| $SiO_2$ | .14 | .055 | .09 | .06 | .05 | .16 |
| $Al_2O_3$ | .01 | .01 | | | .01 | .02 |
| $(CaMg)CO_3$ | .04 | .14 | | | | |
| KCl | .51 | 1.07 | 1.12 | 1.14 | 1.21 | 2.93 |
| NaCl | 3.51 | 7.44 | 35.06 | 45.59 | 60.99 | 19.16 |
| $Na_2SO_4$ | 1.89 | 3.18 | 25.44 | 26.70 | 19.01 | 5.70 |
| $Na_2CO_3$ | 40.87 | 43.75 | 22.84 | 18.19 | 12.51 | 55.04 |
| $NaHCO_3$ | 30.65 | 30.12 | 10.53 | 4.06 | 3.88 | 4.09 |
| $Na_2B_2O_4$ (sodium borate) | ..... | ..... | ..... | ..... | ..... | 2.01 |
| | 100.22 | 100.37 | 99.41 | 100.17 | 99.91 | 100.14 |

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Another series of crystallizations was made at the same time (series B). In this, the first crop, B1 was collected when the mother liquor stood at a specific gravity of 1.285 at $\frac{80°}{26.67°}$; second crop, B2 with mother liquor of 1.325 at $\frac{81°}{27.22°}$; third crop, B3, mother liquor of 1.323 at $\frac{75°}{23.89°}$, and B4 under the same circumstances as A5.

| | B1. | B2. | B3. | B4. |
|---|---|---|---|---|
| $H_2O$ at 120° C. | 18.68 | 7.35 | 2.37 | 9.30 |
| $H_2O$ at red heat | .43 | .41 | .38 | 1.30 |
| Insoluble | .17 | | | |
| $SiO_2$ | .27 | .04 | .04 | .21 |
| $Al_2O_3$ | Trace. | .02 | | |
| CaO | .05 | | | |
| MgO | .02 | | | |
| $SO_3$ | 1.49 | 12.44 | 13.55 | 3.59 |
| Cl | 3.70 | 22.03 | 35.50 | 14.74 |
| $CO_2$ | 34.72 | 15.31 | 6.10 | 23.25 |
| $Na_2O$ | 40.87 | 46.39 | 49.61 | 47.62 |
| $K_2O$ | .65 | .63 | .73 | 2.21 |
| $B_2O_3$ | | | | *1.10 |
| | 101.05 | 104.62 | 108.28 | 103.32 |
| | .83 | 4.96 | 8.00 | 3.32 |
| | 100.22 | 99.66 | 100.28 | 100.00 |

*Specific gravity of mother liquor.*

| | |
|---|---|
| B1 | 1.285 (80°) |
| B2 | 1.325 (81°) |
| B3 | 1.323 (75°) |
| B4 | 1.300 (57°) |

* By difference.

*Hypothetical combination.*

| | B1. | B2. | B3. | B4. |
|---|---|---|---|---|
| $H_2O$ | 15.97 | 6.89 | 2.69 | 10.51 |
| Insoluble | .17 | | | |
| $SiO_2$ | .27 | .04 | .04 | .21 |
| $Al_2O_3$ | Trace. | .02 | | |
| $(CaMg)CO_3$ | .07 | | | |
| KCl | 1.02 | 1.00 | 1.15 | 3.51 |
| NaCl | 5.30 | 35.51 | 57.60 | 21.60 |
| $Na_2SO_4$ | 2.62 | 22.08 | 24.24 | 6.31 |
| $Na_2CO_3$ | 42.33 | 25.00 | 14.02 | 54.91 |
| $NaHCO_3$ | 32.47 | 9.12 | .54 | .87 |
| $Na_2B_2O_4$ | | | | 2.08 |
| | 100.22 | 99.66 | 100.28 | 100.00 |

In B4 the boric acid, which was proved to exist in some quantity, was estimated by difference, as the process for its determination is tedious, and exact figures for this substance in cases like the present are of

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little consequence. In the hypothetical combination the neutral borate $Na_2B_2O_4$ is given instead of borax or the acid borate $Na_2B_4O_7$. The latter can hardly be supposed to exist in such strongly alkaline solutions as those which produced A5 and B4. In the original water the acid borate is set down as probably existing, since a considerable excess of $CO_2$ is there present, which decomposes the neutral borate, forming $Na_2B_4O_7+Na_2CO_3$.[1]

DISCUSSION OF RESULTS.

In comparing these analyses let us first consider "crop 1886," A1 and B1. These are the first crops of a solar evaporation, and are the only ones of any technical importance, unless suitable processes can be devised for utilizing the mother liquors, which by simple evaporation yield products of too low grade for the market, where the value is fixed by the percentage of $Na_2CO_3$ in the ash and the proportion of other salts must not exceed certain limits.

Compared in this way, crop 1886 mother liquor 1.280 is the purest, B1, mother liquor 1.285, comes next, and A1, mother liquor 1.312, is the worst. It is evident, therefore, that if the first crop is to be used directly for making soda ash the concentration should not be allowed to run as far as 1.280, but, as, in such a case, the crop would be a comparatively small one, the advantages of a recrystallization are plainly indicated by comparison of the crop of 1886 with the "best" and "crude" of the crop of 1887. (See page 76.)

The rapid increase of $SO_3$ and Cl is shown by the two series. $SO_3$ reaches its maximum in A3 and B3 and then rapidly declines, while Cl is greatest in A4 and B3. $NaHCO_3$ is deposited in great part in the early stages of the crystallization; so that, when afterwards, most of the sulphates and chlorides are got rid of, the remaining solution contains a very large proportion of $Na_2CO_3$, which separates when the solution is chilled.

The solar evaporation thus divides itself into three stages; first, the deposition of a comparatively pure compound of $Na_2CO_3$ and $NaHCO_3$; second, the formation of a product consisting in great part of sulphates and chlorides; and third, the production of a mother liquor requiring an artificial heat for its further evaporation, but rich in $Na_2CO_3$, and containing the major portion of the potash and boric acid.

*Fractional crystallization of water of Mono Lake.*—In this connection it will be interesting to compare the results of a similar series of crystallizations of some water from Mono Lake. This water had been concentrated by heating, and consequently most of the bicarbonate was reduced to normal carbonate; besides, the total quantity at disposal was so small that the results are not very reliable, but will show the general rule.

[1] Gmelin-Kraut: Anorg. Chem. II, 1. p. 157.



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The concentrated water was about one-sixth of the original in volume, and had a specific gravity of 1.210. On being exposed to a dry atmophere for quite a long period it began to deposit cubes of NaCl, and then a quantity of indefinite crystals (C1). These were collected, the mother liquor showing a specific gravity of 1.348. In time this solution gave a second crop C2, but did not vary in specific gravity. When, however, the third crop C3, had been obtained, the mother liquor showed a reduced specific gravity of 1.335. Continued evaporation yielded C4 mother liquor 1.361, and C5, mother liquor 1.381. The final evaporation to dryness gave C6. C5, when examined, was a mixture of cubes of NaCl resting on a layer of salts which, however, was too small in quantity to give accurate determinations, since, though carefully ground and mixed, concordant results could not be obtained. In such cases, where different salts crystallize together, concordant results can be looked for only when the sample, carefully weighed, is dissolved in water and portions of the solution weighed out for analysis. The figures obtained show that the composition of C5 lies between C4 and C6.

| | C1. | C2. | C3. | C4. | C6. |
|---|---|---|---|---|---|
| Sp. gr. mother liquor | 1.348 | 1.348 | 1.335 | 1.361 | Dry. |
| $H_2O$ | 15.21 | 12.15 | .80 | 4.59 | 11.37 |
| $SiO_2$ | .07 | .17 | .16 | trace. | .13 |
| CaO | .03 | .08 | .03 | .04 | .01 |
| MgO | .23 | .22 | .01 | trace. | trace. |
| $SO_3$ | 1.54 | 7.99 | 27.68 | 9.14 | 3.75 |
| Cl | 11.97 | 13.29 | 18.40 | 37.20 | 26.87 |
| $CO_2$ | 29.91 | 24.24 | 8.15 | 7.97 | 14.24 |
| $Na_2O$ | 43.02 | 44.45 | 48.39 | 49.02 | 39.93 |
| $K_2O$ | .43 | .43 | .30 | .45 | 9.60 |
| | 102.41 | 103.02 | 103.92 | 108.41 | 105.90 |
| O=Cl | 2.69 | 3.00 | 4.14 | 8.38 | 6.05 |
| | 99.72 | 100.02 | 99.78 | 100.03 | 99.85 |

*Hypothetical combination.*

| | C1. | C2. | C3. | C4. | C6. |
|---|---|---|---|---|---|
| $H_2O$ | 12.28 | 10.98 | .69 | 4.18 | 11.31 |
| $SiO_2$ | .07 | .17 | .16 | ..... | .13 |
| $CaCO_3$ | .05 | .14 | .05 | .07 | .02 |
| $MgCO_3$ | .48 | .46 | .02 | ..... | ..... |
| KCl | .69 | .69 | .47 | .71 | 15.20 |
| NaCl | 19.18 | 21.34 | 29.96 | 60.75 | 32.36 |
| $Na_2SO_4$ | 2.73 | 14.18 | 49.13 | 16.22 | 6.65 |
| $Na_2CO_3$ | 36.87 | 41.07 | 18.27 | 14.22 | 33.69 |
| $NaHCO_3$ | 27.37 | 10.99 | 1.03 | 3.88 | .49 |
| | 99.72 | 100.02 | 99.78 | 100.03 | 99.85 |

The comparison of series C with A and B illustrates still further the rule of deposition for each of the constituent salts. In addition we

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see that while the percentage of chlorides in C1 is much greater than in the others, the amount of sulphates varies very slightly, though this variation may give us important hints, as it may have an especial bearing upon the separation of the carbonates.

The relation of $Na_2CO_3$ and $NaHCO_3$ is brought out by comparing the percentages of the two salts with their molecular weights, $Na_2CO_3=106$, $NaHCO_3=84$, which gives us the following results:

| | Per cent. Cl. | Per cent. $SO_3$. | Per cent. $NaHCO_3$; per cent. $Na_2CO_3$. |
|---|---|---|---|
| Crop 1886..... | 2.36 | 1.07 | 30.65 : 40.87 :: 84 : 112 |
| A1..... | 4.84 | 1.79 | 30.12 : 43.75 :: 84 : 122 |
| B1..... | 3.70 | 1.49 | 32.47 : 42.33 :: 84 : 109.5 |
| C1..... | 11.97 | 1.54 | 27.37 : 36.87 :: 84 : 113.1 |

The true molecular proportion would be 84 : 106, so that in each case we have an excess of $Na_2CO_3$, the excess being greatest in A1 where the percentage of $SO_3$, 1.79, is the largest. Strictly speaking, only A1 and B1 are really comparable, having been obtained under like condition, while crop 1886 was the product of a large mass of liquid, and the solution C from another locality had been boiled.

A1, as shown by the specific gravity of the mother liquor, is the product of a greater degree of concentration than B1, and is less pure, which, as already stated, seems to fix the limit of production of a first crop, for Owen's Lake water, at the point where the mother liquor has reached a specific gravity of 1.280, or even something less, since above this point the amount of sulphates and chlorides rapidly increase without compensation by increase of carbonates.

We are now prepared to study the nature of this combination of $Na_2CO_3$ and $NaHCO_3$ on which such stress is laid, for reasons that will appear in the following discussion:

## URAO.

*Native urao from Venezuela.*—The occurrence in Venezuela of this form of native alkali has already been described on page 40, and on page 35, it was stated that this material is found in many places, is of the greatest importance in the technology of natural soda, and would be treated in a separate section. Referring to page 41 for Boussingault's description of this salt, and repeating the results there given, we have:

| Found. | | Hypoth. comp. | |
|---|---|---|---|
| $Na_2O$ ..... | 41.22 | $Na_2CO_3$ ..... | 46.98 |
| $CO_2$..... | 39.00 | $NaHCO_3$ ..... | 37.24 |
| $H_2O$ ..... | 18.80 | $H_2O$ ..... | 14.80 |
| Impurities.... | .98 | Impurities.... | .98 |
| | 100.00 | | 100.00 |

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The impurities are insoluble matter with chlorides and sulphates, all of which can be deducted when we desire to calculate the formula of the compound as these salts are under the circumstances anhydrous (see page 29), hence merely diminish the percentage of urao in the original material.

The formula already given for urao is

$$Na_2CO_3, NaHCO_3+2H_2O,^1$$

and if we deduct the impurities from Boussingault's analysis and recalculate the residue to 100 per cent. and likewise calculate the theoretical percentages for the above formula, we shall have

| | Impurities deducted. | Theoretical. $Na_2CO_3$ NaH $CO_3+2$ $H_2O$. | Difference. |
|---|---|---|---|
| $Na_2O$ | 41.63 | 41.15 | +.48 |
| $CO_2$ | 39.38 | 38.94 | +.44 |
| $H_2O$ | 18.99 | 19.91 | −.92 |
| | 100.00 | 100.00 | |

*Theoretical composition.*

| | | | |
|---|---|---|---|
| $Na_2CO_3$ | 47.44 | 46.90 | +.54 |
| $NaHCO_3$ | 37.61 | 37.17 | +.44 |
| $2H_2O$ | 14.95 | 15.93 | −.98 |
| | 100.00 | 100.00 | |

Again, if we take the proportion between the $Na_2CO_3$ and the $NaHCO_3$ we have

$$Na_2CO_3 : NaHCO_3 :: 106 : 84 :: 47.44 : 37.50,$$

while the amount of $NaHCO_3$ found is 37.61, a difference of only 0.11 per cent. Hence Boussingault's urao is an almost theoretically pure salt, showing only a small loss of water and a trifling increase of $NaHCO_3$.

*Native urao from Egypt.*—The analysis of Egyptian soda by Remy, given on page 39, if calculated in the same manner, shows a remarkable agreement with the foregoing. In his original paper, Remy gives as found $SiO_2$, 0.144; CaO, 0.078; $CO_2$, 32.160; $SO_3$, 1.210, and Cl, 4.95 per cent., hence by reducing his analysis, as given, to its constituents we have

[1] Laurent: Ann. de Chimie, series 3, vol. 36, p. 348.

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| | Recalculated. | | Hypothetical composition. | |
|---|---|---|---|---|
| Insoluble | 4.106 | Insoluble | 4.106 | |
| $SiO_2$ | .144 | $SiO_2$ | .144 | |
| $SO_3$ | 1.210 | $CaCO_3$ | .20 | =14.758 |
| Cl | 4.950 | NaCl | 8.160 | |
| $CO_2$ | 32.160 | $Na_2SO_4$ | 2.148 | |
| CaO | .078 | $Na_2CO_3$ | 38.45 | |
| $Na_2O$ | 39.080 | $NaHCO_3$ | 30.70 | |
| $H_2O$ | 19.669 | $H_2O$ | 16.38 | |
| | 101.397 | | | |
| O=Cl | 1.110 | | | |
| | 100.287 | | 100.288 | |

If now we deduct from the last column the 14.758 of impurities we shall get column *a*; if we recalculate to 100.00, column *b*; while if we figure the theoretical proportions of $NaHCO_3$ and $H_2O$ required for the 44.95 per cent. of $Na_2CO_3$ in *b*, we obtain column *c*, and consequently the differences.

| | *a* | *b* | *c* | Difference. |
|---|---|---|---|---|
| $Na_2CO_3$ | 38.45 | 44.95 | 44.95 | 0.00 |
| $NaHCO_3$ | 30.70 | 35.90 | 35.62 | + .28 |
| $H_2O$ | 16.38 | 19.15 | 15.27 | +3.88 |
| | 85.53 | 100.00 | | |

*True character of trona, or the native sesquicarbonate.*—From this it appears that Remy's trona, after deducting the impurities, is urao with a very slight excess of $NaHCO_3$, but 3.88 per cent. excess of $H_2O$. Whether or not the presence of this excess of water is to be ascribed to the $Na_2SO_4$ will become clearer as we go on.

Klaproth[1] in 1802 published the following analysis of a natural soda from near Fezzan in the Desert of Sahara:

| | As published. | Impurities deducted. | | Hypothetical composition. |
|---|---|---|---|---|
| $Na_2O$ | 37.00 | 37.95 | $Na_2CO_3$ | 35.88 |
| $CO_2$ | 38.00 | 38.97 | $NaHCO_3$ | 45.96 |
| $H_2O$ | 22.50 | 23.08 | $H_2O$ | 18.16 |
| $Na_2SO_4$ | 2.50 | | | |
| | 100.00 | 100.00 | | 100.00 |

To this mineral the name trona has been given and it is considered as a native sesquicarbonate of sodium. As previously stated (page 35)

[1] Klaproth: Beiträge zur Chem. Kenntniss d. Mineralkörper, III, 1802, p. 83. Also see Dana's Mineralogy, article Trona.

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"sesquicarbonate" is the name given to a supposed compound of $Na_2CO_3$ and $NaHCO_3$ in the proportion of one molecule of $Na_2CO_3$ to two of $NaHCO_3$, with the addition of water. As by the dualistic formula formerly in use sodium monocarbonate was written NaO, $CO_2$, and the bicarbonate NaO, HO, $2CO_2$, the formula of the compound was written 2 NaO, 3 $CO_2$ whence its name, the HO being omitted, not being considered an essential constituent. The formula of the theoretical sesquicarbonate is $Na_2CO_3$, 2 $NaHCO_3$+3 $H_2O$, which gives us the following percentages with which Klaproth's results are compared:

| | Theoretical. | Klaproth. | Difference. |
|---|---|---|---|
| $Na_2CO_3$ | 32.32 | 35.88 | +3.56 |
| $2NaHCO_3$ | 51.22 | 45.96 | —5.26 |
| $3H_2O$ | 16.46 | 18.16 | +1.70 |
| | 100.00 | 100.00 | |

These differences are too great to be considered as slight variations from a theoretical formula, such as are shown by Boussingault's mineral. If Klaproth's trona be compared with a theoretical urao the differences are still larger being —11.02 $Na_2CO_3$, +8.79 $NaHCO_3$ and +2.23 $H_2O$, hence we see that we have here a mixture to which neither formula can be assigned.

Joffre[1] analyzed a trona stated to have come from the same locality and supposed to be the same as Klaproth's. He describes the mineral thus:

Incrustations of about 2 to 3 centimeters in thickness. It is in masses which are crystalline and perfectly white, except the lower part which is colored by a trace of oxide of iron.

After giving the figures of the analysis below, he says:

The first three numbers correspond to sesquicarbonate of soda, contaminated with a little carbonate of soda * * * should be included in the mineral species named urao. The presence of carbonate of lime and of chloride of sodium may give confirmation to the views of M. Berthollet concerning the origin of natural soda, which he ascribes to the reaction of these two substances upon each other.

| | Joffre. | Impurities deducted. | | Hypothetical composition. | Theoretical sesquicarbonate. | Difference. |
|---|---|---|---|---|---|---|
| $Na_2O$ | 39.41 | 40.01 | $Na_2CO_3$ | 40.08 | 32.32 | +7.76 |
| $CO_2$ | 39.58 | 40.18 | $NaHCO_3$ | 44.93 | 51.22 | —6.29 |
| $H_2O$ | 19.52 | 19.81 | $H_2O$ | 14.99 | 16.46 | —1.47 |
| Sand | .53 | | | | | |
| $Fe_2O_3$ | .01 | | | | | |
| $CaCO_3$ | .05 | | | | | |
| NaCl | .46 | | | | | |
| $Na_2SO_4$ | .44 | | | | | |
| | 100.00 | 100.00 | | 100.00 | 100.00 | |

[1] Joffre: Bull. Societé Chimique, vol 12, p. 102.

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The differences are, therefore, still greater than in Klaproth's trona, and in fact, as far as is known, the only analyses of natural soda which give a composition at all near to true sesquicarbonate are those of Popp.[1]

Popp's specimens came from Egypt, and are described as "distinctly crystalline salt crusts almost an inch thick," No. 1 was "an aggregate of small, transparent prismatic crystals, the prisms being clearly distinguishable."

| | No. 1. | No. 2. | No. 3. |
|---|---|---|---|
| Insoluble | 1.65 | 1.35 | .40 |
| CaO | .55 | trace. | ..... |
| $SO_3$ | 1.65 | 13.53 | 37.56 |
| Cl | 5.11 | 20.25 | 1.58 |
| $CO_2$ | 33.15 | 16.55 | 13.50 |
| $Na_2O$ | 36.34 | 43.68 | 43.10 |
| $H_2O$ | 22.50 | 8.87 | 4.05 |
| | 100.95 | 104.23 | 100.19 |
| Deduct O=Cl | 1.15 | 4.56 | .35 |
| | 99.80 | 99.67 | 99.84 |

*Hypothetical composition.*

| | No. 1. | No. 2. | No. 3. |
|---|---|---|---|
| Insoluble | 1.65 | 1.35 | .40 |
| $Na_2SO_4$ | 2.93 | 24.01 | 66.67 |
| NaCl | 8.42 | 33.38 | 2.61 |
| $CaCO_3$ | .99 | ..... | ..... |
| $Na_2CO_3$ | 25.81 | 13.40 | 10.60 |
| $NaHCO_3$ | 42.00 | 20.93 | 17.37 |
| $H_2O$ | 18.00 | 6.60 | 2.19 |
| | 99.80 | 99.67 | 99.84 |

Deducting impurities as before and recalculating, we have,

| | No. 1. | No. 2. | No. 3. |
|---|---|---|---|
| $Na_2CO_3$ | 30.08 | 32.74 | 35.15 |
| $NaHCO_3$ | 48.94 | 51.13 | 57.59 |
| $H_2O$ | 20.98 | 16.13 | 7.26 |
| | 100.00 | 100.00 | 100.00 |

From the composition of No. 1, Popp deduced the formula $Na_2CO_3$, 2 $NaHCO_3+4\,H_2O$; No. 2 is close to $Na_2CO_3$, $2NaHCO_3+3\,H_2O$, while No. 3 approximates $Na_2CO_3$, $2\,NaHCO_3+H_2O$. The theoretical percentages

[1] Popp: Ann der Chemie u. Pharm., vol. 155, p. 348.

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of these degrees of hydration and the differences from the respective analyses are as follows:

| | $4H_2O$. | Difference No. 1. | $3H_2O$. | Difference No. 2. | $1H_2O$. | Difference No. 3. |
|---|---|---|---|---|---|---|
| $Na_2CO_3$ | 30.64 | —.56 | 32.32 | +.42 | 36.30 | —1.15 |
| $NaHCO_3$ | 48.55 | +.39 | 51.22 | —.09 | 57.54 | +.05 |
| $H_2O$ | 20.81 | +.17 | 16.46 | —.33 | 6.16 | +1.10 |
| | 100.00 | | 100.00 | | 100.00 | |

These results are very remarkable and would appear to settle affirmatively the existence of true sesquicarbonate in nature, but we shall have occasion to refer to them later and give reasons for further doubt. The analysis of the incrustation from Brown's Station, Nev., given on page 56, may be disregarded in this connection, as the existence of the sesquicarbonate appears to have been assumed and one of the determinations obtained "by difference."

*Artificial production of sesquicarbonate.*—The artificial production of sesquicarbonate has been claimed by both Winkler and Hermann.

Winkler,[1] by dissolving 100 parts $Na_2CO_3$ and 152 parts $NaHCO_3$ in 1,920 parts of water and carefully adding 1,920 parts of 80 per cent. alcohol, so that the two liquids did not mix, obtained, after the lapse of several days, fine, transparent, non-efflorescent, acicular crystals. These adhered to the sides of the vessel and with them were crystals of hydrated monocarbonate and bicarbonate, the latter principally on the bottom. His analysis of the acicular crystals is given below.

Hermann[2] mixed thoroughly $Na_2CO_3$, $10H_2O$ and $NaHCO_3$ in the proportion of 1 : 2, melted the mixture in the water of crystallization, and allowed the cold mass to remain in damp air for some weeks. At the end of that time the mass had become crystalline and its cavities were lined with crystals of sesquicarbonate, which he analyzed.

Both Winkler and Hermann give as the formula of the salt, $2Na_2O$, $3CO_2+3H_2O$ or $Na_2CO_3, 2NaHCO_3 + 2H_2O$, as is shown by the analyses.

| | Molecular weight. | Theoretical per cent. | Winkler. | Hermann. |
|---|---|---|---|---|
| $2Na_2O$ | 124 | 40.00 | 41.13 | 40.00 |
| $3CO_2$ | 132 | 42.58 | 43.30 | 43.06 |
| $3HO_2$ | 54 | 17.42 | 15.57 | 16.94 |
| | 310 | 100.00 | 100.00 | 100.00 |

[1] Buchner's Repert. f. Pharm., vol. 48, p. 215.
[2] Journ. f. prakt. Chem., vol. 26, p. 312.

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*Hypothetical composition.*

| | Molecular weight. | Theoretical. | Winkler. | Difference. | Hermann. | Difference. |
|---|---|---|---|---|---|---|
| $Na_2CO_3$ | 106 | 34.20 | 36.33 | +2.13 | 33.02 | −1.18 |
| 2 $NaHCO_3$ | 168 | 54.19 | 53.87 | −.32 | 56.04 | +1.85 |
| 2 $H_2O$ | 36 | 11.61 | 9.80 | −1.81 | 10.94 | −.67 |
| | 310 | 100.00 | 100.00 | ..... | 100.00 | ..... |

By following the directions given by Winkler small needles, such as he describes, were obtained; from these the material for analyses was selected with great care and appeared to be free from the other salts which had crystallized simultaneously. As the latter are sodium bicarbonate, and hydrated monocarbonate, the separation must be carefully made, else results may be obtained showing great variety in the proportions of the two. The amount of salt thus secured was small, but sufficient for the following duplicate analyses:

| | *a* | *b* | | *a* | *b* | Average. |
|---|---|---|---|---|---|---|
| $H_2O$ | 19.19 | 19.31 | $H_2O$ | 14.64 | 14.75 | 14.69 |
| $CO_2$ | 40.01 | 40.01 | $Na_2CO_3$ | 42.72 | 42.67 | 42.70 |
| $Na_2O$ | 40.69 | 40.67 | $NaHCO_3$ | 42.53 | 42.57 | 42.55 |
| | 99.89 | 99.99 | | 99.89 | 99.99 | 99.94 |

These results do not agree with those of Winkler nor with any of the salts described by Popp. Morever, no simple theoretical formula can be assigned to the combination, and we have either a sesquicarbonate plus an excess of $Na_2CO_3$, or what is more probable, urao plus an excess of $NaHCO_3$.

The following table is a comparison of the foregoing analyses. As the proportion of water present varies for each sample, the percentage of $Na_2CO_3$, 2 $NaHCO_3$, or as it may be called "anhydrous sesquicarbonate," is calculated for each, and the excess, whether of monocarbonate or bicarbonate, thus shown.

| | $Na_2CO_3$, 2 $NaHCO_3$. | Excess. | |
|---|---|---|---|
| | *Per cent.* | *Per cent.* | |
| Remy | 62.42 | 18.43 | $Na_2CO_3$ |
| Joffre | 73.28 | 11.73 | $Na_2CO_3$ |
| Klaproth | 74.96 | 6.88 | $Na_2CO_3$ |
| Popp, No. 1 | 77.75 | 1.27 | $NaHCO_3$ |
| Popp, No. 2 | 83.39 | .48 | $Na_2CO_3$ |
| Popp, No. 3 | 90.86 | 1.88 | $NaHCO_3$ |
| Hermann | 85.35 | 3.72 | $NaHCO_3$ |
| Winkler | 87.86 | 2.34 | $Na_2CO_3$ |
| Chatard | 69.40 | 15.85 | $Na_2CO_3$ |

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The other analyses of natural soda which are known show still larger excesses of $Na_2CO_3$ than these. So far, therefore, the evidence in favor of the existence of sesquicarbonate is very unsatisfactory and must remain so until some one has succeeded in producing it by crystallization from aqueous solution by simple evaporation. My own experiments on the artificial formation of urao[1] appear to demonstrate the non-existence of the salt.

In addition to the analyses already given, we have Laugier's[2] examination of a Barbary soda, Pfeiffer's[3] analysis of an East Indian soda, and Wallace's[4] of several samples of soda from the Loonar Lake.

Wallace calls especial attention to the proportion of $CO_2$ to $Na_2O$ as shown by his work, and remarks that although the text-books generally state that the trona from Egypt and other localities consisted of sodium sesquicarbonate, yet the analyses show that the sesquicarbonate and the neutral carbonate are associated in nearly equal proportions, and it appears likewise that under the circumstances in which the deposits were made, a compound of soda was formed that contains nearly four equivalents of soda to five of carbonic acid. In no case had he found the $Na_2O$ and the $CO_2$ to be present in the proportions necessary to form either the neutral carbonate or the sesquicarbonate, and it is his opinion that lack of uniformity in stating the results of analysis was the cause of the error.

Tabulating the results of these analyses we have,

| | Urao. | Excess $Na_2CO_3$. | Urao. | Excess. |
|---|---|---|---|---|
| Allen, Big Lake, Ragtown (p. 52) | 78.39 | 1.32 | 100 | 1.68 |
| Allen, Little Lake, Ragtown (p. 52) | 78.98 | .17 | 100 | .21 |
| Chatard, Little Lake, Ragtown (p. 52) | 56.66 | 20.59 | 100 | 30.34 |
| Woodward, Ruby Valley (p. 56) | 18.30 | 48.48 | 100 | 264.92 |
| Woodward, Deep Creek (p. 56) | 33.38 | 6.50 | 100 | 19.47 |
| Woodward, Antelope Valley (p. 56) | 32.46 | 7.84 | 100 | 24.12 |
| Woodward, Humboldt Valley (p. 56) | 81.45 | 4.55 | 100 | 5.58 |
| Pfeiffer | 6.33 | 30.25 | 100 | 478.00 |
| Laugier | 52.48 | 25.48 | 100 | 48.55 |
| Wallace, Dulla Khar | 75.52 | 12.13 | 100 | 16.06 |
| Wallace, Nummuck Dulla | 5.54 | 2.34 | 100 | 42.24 |
| Wallace, Papree | 38.49 | 8.53 | 100 | 22.16 |
| Wallace, Bhooskee | 23.11 | 8.38 | 100 | 36.26 |

It is evident from the above that while, in each case, there is an excess of the neutral carbonate, the amount of this excess bears no general relation to the amount of urao or of sesquicarbonate present, and we must consider natural soda either as an indefinite mixture of

[1] Pp. 78 et seq.

[2] Laugier: Dingler's Polyt. Jour., vol. 18, p. 482.

[3] Pfeiffer: Journ. f. prakt. Chemie, vol. 61, p. 439.

[4] Wallace: Chem. News, vol. xxvii, p. 203.

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the neutral carbonate and the bicarbonate or as a certain definite compound of these two salts, having the composition either of urao ($Na_2Co_3,NaHCO_3$) or of sesquicarbonate ($Na_2CO_32NaHCO_3$) generally intermixed with an excess of one or the other of the two constituents.

No other combinations of these two substances have, up to the present time, been claimed to exist; the evidence for the sesquicarbonate has been given, and it remains to consider the proof of the existence of urao, not only as an occasionally occurring mineral, but also *the sole natural combination of the two carbonates.*

*Urao from Owen's Lake.*—We have already discussed Boussingault's analysis of the original urao, and showed that this gave percentages remarkably close to the theoretical for the formula

$$Na_2CO_3,NaHCO_3+2H_2O,$$

and on page 59 reference was made to certain salts from Owen's Lake which are now to be considered.

The "best specimen," as there stated, is the result of the spontaneous evaporation of the water of the lake, for although the crystallization occurred in an artificial ground vat and the first crop was redissolved in lake water, yet nothing was added to the water, and solar heat only was the evaporating agent. Hence such a product is purely natural in its character, and must be considered as a "mineral," and not as an artificial substance.

The piece examined was one of several broken from a large fragment of the crystal sheet covering the bottom of the vat. It was a mass about two inches thick, the upper portion of which was well crystallized and translucent; the intermediate part, an interlamination of thin translucent crystallized sheets and of fine granular crystalline white material; the bottom of the specimen is a layer similar to the upper part, but thinner, the crystals being much smaller.

The analysis marked "best specimen" was made from the upper portion, which presented a columnar radiated structure, the crystals being so grown together that the terminations alone were visible and these so combined together that each combination had a curved ridge-like termination or cockscomb form. The specific gravity of the material was 2.1473 taken in benzol at 21.7° C. The "crude" is the fine granular material from the central part of the specimen, and is the undissolved residue of the first crop.

The "twig" urao was formed on a branching grass root which happened to be suspended in the water of a small natural lagune on the east side of the lake. It has the form of a stout twig or of a branching coral, each of the branches forming a cylinder, a section of which shows the radiated structure, while the surface of the cylinder is rough, the curved edges of the crystal aggregates giving a lenticular appearance. The color is brownish, and one side of the specimen shows crystals of NaCl and much sand, as the evaporation of the water finally left it lying on the mud of the bottom.

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The "lagune" specimen is from another small lagune near by, and consists of a thin sheet, the surfaces of which are rough like the preceding specimen. Color pink, due to organic matter. (See p. 95).

"Beach vat." This was formed in a vat dug in the beach and allowed to fill by seepage from the surrounding soil. Analyses of this seepage water will be found on page 94.

| | Best specimen. | | | Average. |
|---|---|---|---|---|
| Insoluble (inorganic) | ..... | ..... | ..... | .02 |
| Cl | .195 | .191 | ..... | .193 |
| $SO_3$ | .707 | .697 | ..... | .702 |
| $CO_2$ | 38.18 | 38.11 | 38.10 | 38.13 |
| $Na_2O$ | 40.98 | 41.01 | ..... | 40.995 |
| $H_2O$ | 20.12 | 20.09 | 20.00 | 20.07 |
| | | | | 100.110 |
| Deduct O=Cl | ..... | ..... | ..... | .04 |
| | | | | 100.07 |

| | Crude. | Twig. | Lagune. | Beach vat. |
|---|---|---|---|---|
| Insoluble (inorganic) | .22 | 2.92 | .40 | 4.10 |
| Insoluble (organic) | ..... | .14 | .12 | .27 |
| $SiO_2$ | .10 | .05 | .09 | .04 |
| Cl | 1.57 | 2.73 | .21 | 1.83 |
| $SO_3$ | .79 | .76 | .63 | .84 |
| $CO_2$ | 37.00 | 35.24 | 37.50 | 35.10 |
| $Na_2O$ | 41.26 | 40.22 | 40.08 | 39.36 |
| CaO | ..... | ..... | .06 | ..... |
| $K_2O$ | ..... | ..... | trace | ..... |
| MgO | ..... | ..... | .02 | ..... |
| $H_2O$ | 19.62 | 18.31 | 19.94 | 18.58 |
| | 100.56 | 100.37 | 99.05 | 100.12 |
| O=Cl | .35 | .61 | .05 | .41 |
| | 100.21 | 99.76 | 99.00 | 99.71 |

*Hypothetical composition.*

| | Best specimen. | Crude. | Twig. | Lagune. | Beach vat. |
|---|---|---|---|---|---|
| Insoluble | .02 | .22 | 3 06 | .52 | 4.37 |
| $SiO_2$ | ..... | .10 | .05 | .09 | .04 |
| $CaCO_3$ | ..... | ..... | ..... | .10 | ..... |
| $MgCO_3$ | ..... | ..... | ..... | .04 | ..... |
| NaCl | .32 | 2.58 | 4.50 | .34 | 3.01 |
| $Na_2SO_4$ | 1.25 | 1.39 | 1.35 | 1.12 | 1.49 |
| $Na_2CO_3$ | 45.86 | 45.28 | 42.46 | 48.73 | 42.36 |
| $NaHCO_3$ | 36.46 | 34.74 | 33.63 | 31.49 | 33.44 |
| $H_2O$ | 16.16 | 15.90 | 14.71 | 16.57 | 15.00 |
| | 100.07 | 100.21 | 99.76 | 99.00 | 99.71 |

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Deducting NaCl and other impurities, as before, and recalculating to 100 per cent., we have—

| | Best. | Crude. | Twig. | Lagune. | Beach vat. |
|---|---|---|---|---|---|
| $Na_2CO_3$ ..... | 46.57 | 47.20 | 46.76 | 50.35 | 46.65 |
| $NaHCO_3$ ..... | 37.03 | 36.22 | 37.04 | 32.53 | 36.83 |
| $H_2O$ ..... | 16.40 | 16.58 | 16.20 | 17.12 | 16.52 |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

Finally, if we compare these new percentages with the theoretical figures for urao, already given, we shall find the following differences:

| | Theoretical. | Best. | Crude. | Twig. | Lagune. | Beach vat. |
|---|---|---|---|---|---|---|
| $Na_2CO_3$ ..... | 46.90 | —.33 | +.30 | —.14 | +3.45 | —.25 |
| $NaHCO_3$ ..... | 37.17 | —.14 | —.95 | —.13 | —4.64 | —.34 |
| $H_2O$ ..... | 15.93 | +.47 | +.65 | +.27 | +1.19 | +.59 |

These small differences show that each of the samples is urao. In each case there is a varying amount of NaCl, $Na_2SO_4$ and other impurities to be deducted, but when this is done, the residue in four out of the five samples has a very close agreement with the formula of the mineral. In the case of the "lagune" the differences are quite large, but as the local circumstances attending the production of each specimen are well known, the explanation is simple.

The "best specimen," although obtained like the others by the spontaneous evaporation of the natural water, is, in effect, a recrystallization occuring in a shallow basin of no great extent. The process was slow, the insoluble impurities had time to settle, and the product was gathered as soon as a tendency to deposit NaCl was observed. That this was successfully done is shown by the analysis, but the percentage of $Na_2SO_4$ is not materially different from that of the other specimens made under less favorable circumstances. That this is to be expected follows from what we know of the relative solubility of the different salts. The solubility of NaCl is but little affected by changes of temperature, which have great influence on that of the sulphate and carbonates. The sulphate is not only more soluble than urao, but is also present in much smaller proportion in this water, hence it is not deposited to any extent until most of the urao has separated. Afterward the relative amount rapidly increases, as has been shown by the series of crystallizations of the water of Owen's and Mono Lakes.

The "crude," as already stated, is that portion of the first crystallization which was not redissolved. As the first crystallization was allowed to go on till NaCl had been deposited in some quantity, the

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increased amount of this salt is accounted for; but as the process was then interupted, little more sulphate is found in this than in the purest specimens.

The "twig" urao shows smaller differences from the theoretical proportions, than any of the others. The grass root on which it formed was suspended in the water of the shallow natural basin so that the crystallization proceeded evenly at all points. It was only when the decrease of the water left the specimen lying on a mud bank that the salt crystals and sand adhered to it. If these impurities are deducted, the remainder is a practically pure urao.

The "beach vat" made by spontaneous evaporation of a lye differing from the lake water in having a larger percentage of $NaHCO_3$ and a smaller proportion of $Na_2SO_4$, is also very close in the relations of the urao constituents.

Finally we have the "lagune" urao. This was found on the border of the small lagune which was then dry. It is apparently the result of an interchanging concentration and dilution of the mother-liquor in which it was formed. As the water in such a shallow basin evaporates, the tendency is to leave a crust of very pure urao at the edge of the basin, the deposit towards the center becoming more and more impure as the concentrating liquid deposits its salt and sulphate, and becomes, as the experiments show, a comparatively pure solution of monocarbonate. If then the basin be refilled by seepage, as would be the case when the lake rises, as it does in the spring, the solution would contain a larger proportion of the neutral carbonate, and in consequence, on reconcentration, leave on its edges a urao containing an excess of hydrated monocarbonate. If we calculate the amount of urao present in this sample we shall find that the excess of $Na_2CO_3$ and $H_2O$ is almost exactly the amount required for $Na_2CO_3+2H_2O$.

| "Lagune." | | Urao. | | $Na_2CO_3+2H_2O$. | |
|---|---|---|---|---|---|
| $Na_2CO_3$ | 48.73 = | 39.73 | + 9.00 | | .... |
| $NaHCO_3$ | 31.49 = | 31.49 | .... | | .... |
| $H_2O$ | 16.57 = | 13.49 | + 3.06 | + | .02 |
| Impurities | 2.21 = | ..... | .... | | 2.21 |
| | 99.00 = | 84,71 | + 12.06 | + | 2 22 |

The deficiency of one per cent. in the analysis is in this respect unfortunate, but can not be easily explained. The analytical figures given are averages, derived from two or more closely agreeing determinations of each constituent, the list of which comprises everything that can be supposably present.

*Artificial urao.*—In order to determine the conditions under which urao is formed, and also to find out if, by spontaneous evaporation, the sesquicarbonate or any other combination of the mono and bicarbonate might be formed, the following series of experiments was undertaken.

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Some of the analytical results already obtained appeared to give some indications of the existence of a mixed carbonate having a formula $2Na_2CO_3 + NaHCO_3 + x H_2O$. If this could be separated in a pure state and the sesquicarbonate also obtained, we should have the following series:

| | |
|---|---|
| $Na_2CO_3$ | Mono-carbonate. |
| $Na_2CO_3 + \frac{1}{2} NaHCO_3$ | Supposed salt. |
| $Na_2CO_3 + NaHCO_3$ | Urao. |
| $\frac{1}{2}Na_2CO_3 + NaHCO_3$ | Sesquicarbonate. |
| $NaHCO_3$ | Bicarbonate |

For this investigation a number of solutions were prepared, each of which contained $Na_2CO_3$, $NaHCO_3$, and NaCl, the amount of each salt employed having a certain definite relation to its molecular weight. NaCl was used because its presence appears to exert a favorable influence on the crystallization of the mixed carbonates.

Solution No. 1 was intended to produce the "supposed salt," and was therefore made up as follows: 10.5 grams $NaHCO_3$ ($=\frac{1}{8}$ molecule) 26.5 grams $Na_2CO$ ($=\frac{1}{4}$ molecule) were dissolved in water. To this solution were added 26.5 grams $Na_2CO_3$ and 29.25 grams NaCl. These latter amounts are purely empirical, an excess of $Na_2CO_3$ seemed to be needed, so that a quantity equal to that already present was added, and as we then have half a molecule, 29.5 grams $= \frac{1}{2}$ mol. NaCl was used. The solutions as evaporated contained:

| | | |
|---|---|---|
| No. 1. | 10.05 grams $NaHCO_3$ | $= \frac{1}{8}$ molecule. |
| | 53.00 grams $Na_2CO_3$ | $= \frac{1}{4}$ molecule. |
| | 29.25 grams NaCl | $= \frac{1}{2}$ molecule. |
| No. 2. | 21.00 grams $NaHCO_3$ | $= \frac{1}{4}$ molecule. |
| | 53.00 grams $Na_2CO_3$ | $= \frac{1}{4}$ molecule. |
| | 29.25 grams NaCl | $= \frac{1}{2}$ molecule. |

This proportion was expected to yield urao:

| | | |
|---|---|---|
| No. 3. | 42.00 grams $NaHCO_3$ | $= \frac{1}{2}$ molecule. |
| | 53.00 grams $Na_2CO_3$ | $= \frac{1}{2}$ molecule. |
| | 29.25 grams NaCl | $= \frac{1}{2}$ molecule. |

The amount of $NaHCO_3$ being twice as great as in No. 2, there was a possibility of the formation of sesquicarbonate.

In the course of six weeks No. 1 had deposited a crop of acicular crystals. The mother liquor was poured off, leaving a large group of small but good crystals, and a number of smaller groups. These were collected and carefully dried between filter paper, remaiuing perfectly transparent and unaltered in the air. In the course of another week the mother liquor yielded a second crop of acicular crystals.

No. 2 deposited at first some crystalline scales, afterwards acicular crystals were formed; this material was collected, and the scales were carefully separated from the other crystals.

No. 3 behaved like No. 2, except that the crop of scales was larger.

The salts thus obtained were analyzed, giving the following results.

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The figures for No. 1 are averages of two closely agreeing determinations of each constituent:

| | No. 1, first crop acicular. | No. 2, first crop scales. |
|---|---|---|
| $H_2O$ | 19.58 | 11.78 |
| $CO_2$ | 38.73 | 51.69 |
| $Na_2O$ | 40.07 | 36.54 |
| NaCl | 1.46 | .51 |
| | 99.84 | 100.52 |

*Hypothetical combination.*

| | | |
|---|---|---|
| $H_2O$ | 15.37 | 1.25 |
| $Na_2CO_3$ | 43.69 | .42 |
| $NaHCO_3$ | 39.32 | 98.34 |
| NaCl | 1.46 | .51 |
| | 99.84 | 100.52 |

By calculating the percentage of urao in each of these salts we find,

| | No. 1. | | | No. 2. | | |
|---|---|---|---|---|---|---|
| | Urao. | Bicarbonate. | Residue. | Urao. | Bicarbonate. | Residue. |
| $H_2O$ | 14.84 | ..... | .53 | .14 | ..... | 1.11 |
| $Na_2CO_3$ | 43.69 | ..... | ..... | .42 | ..... | ..... |
| $Na_2HCO_3$ | 34.62 | 4.70 | ..... | .33 | 98.01 | ..... |
| NaCl | ..... | ..... | 1.46 | ..... | ..... | .51 |
| | 93.15 | 4.70 | 1.99 | .89 | 98.01 | 1.62 |

We see therefore that No. 1, 1st crop, is urao, plus 4.70 $NaHCO_3$, while in No. 2, 1st crop, the scales are nearly pure bicarbonate.

The scales of No. 3 being in all respects similar to those of No. 2 and of No. 7 (to be described later), were considered as being $NaHCO_3$, and were not analyzed.

In the mean time other solutions had been prepared, in which not only the relative proportions of $Na_2CO_3$ and $NaHCO_3$ were varied, but also that of NaCl, in order that the proper proportions of a typical solution for the production of urao might be determined.

For this purpose a solution of $Na_2CO_3$ was prepared, 200 $cm^3$ of which contained 53 grams of the salt, the amount taken for each experiment, the other salts being added, together with sufficient water to effect complete solution.

| Solution. | No. 4. | No. 5. | No. 6. | No. 7. | No. 8. | No. 9. |
|---|---|---|---|---|---|---|
| $Na_2CO_3$ | 53.00 | 53.0 | 53.0 | 53.0 | 53.00 | 53.00 |
| $NaHCO_3$ | 21.00 | 10.5 | 10.5 | 42.0 | 5.25 | 5.25 |
| NaCl | 58.5 | 14.62 | 58.5 | 58.5 | 58.5 | 29.25 |

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In preparing No. 4, the $NaHCO_3$ was added in portions to the 200 $cm^3$ of $Na_2CO_3$ solution, which was vigorously shaken after each addition, but to effect complete solution it was necessary to add water until the volume measured 250$cm^3$. To this, the NaCl was added, and the whole again shaken; an emulsion was formed which speedily became solid, so that the vessel could be inverted without loss. Portions of water were gradually added until a clear solution was obtained, the resulting liquid measuring 590$cm^3$. With No. 5 the $NaHCO_3$ dissolved completely without addition of water, but on putting in the NaCl and shaking a solid mass resulted, measuring 220$cm^3$. Water was then added, and the final solution measured 300$cm^3$. The same phenomenon was observed with each of the other preparations, and all were allowed to spontaneously evaporate.

No. 4 deposited at first a quantity of scales, but soon began to form urao. The mother was then poured off and subsequently produced a large crop of urao, the mother liquor of which deposited NaCl in small but very brilliant cubes.

No. 5 formed radiating wisps or sheaves of very good and quite stout acicular crystals (No. 5, 1st crop.) The mother liquor continued to form these crystals and after some time was poured off. This second mother liquor produced in time several large masses of apparently tabular crystals, together with a small quantity of fine needles. These masses were collected, and as they showed a strong tendency to effloresce and a portion placed in a small bottle became partially liquefied at the atmospheric temperature of 32° C. (90° F.), there is no reason to doubt that they were the ordinary decahydrated salt $Na_2CO_3+10H_2O$.

No. 6 yielded a large crop of beautiful groups of radiating acicular crystals (No. 6, 1st crop). The mother liquor continued to form small acicular crystals, finally NaCl in cubes.

No. 7 deposited crystalline scales, and when acicular crystals began to form the mother liquor was poured off and the needles carefully separated from the plates (No. 7, 1st crop). The mother liquor yielded acicular crystals and NaCl.

Nos. 8 and 9 each deposited acicular crystals, and the mother liquor was poured off. The mother liquor of No. 9 formed a quantity of fine needles so matted together as to present a woolly appearance. (No. 9, 2d crop).

| | No. 5, first crop acicular. | No. 6, first crop acicular. | No. 7, first crop scales. | No. 9, second crop acicular, matted. |
|---|---|---|---|---|
| $H_2O$ | 19.54 | 19.42 | 11.63 | 18.91 |
| $CO_2$ | 37.88 | 37.76 | 51.52 | 36.46 |
| $Na_2O$ | 41.02 | 39.85 | 36.49 | 39.32 |
| NaCl | 1.72 | 2.88 | Undet. | 5.58 |
| | 100.16 | 99.91 | 99.64 | 100.27 |



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*Hypothetical composition.*

| | | | | |
|---|---|---|---|---|
| $H_2O$ | 15.96 | 15.55 | .92 | 15.41 |
| $Na_2CO_3$ | 49.00 | 45.29 | .64 | 46.60 |
| $HaHCO_3$ | 33.48 | 36.19 | 98.08 | 32.68 |
| NaCl | 1.72 | 2.88 | Undet. | 5.58 |
| | 100.16 | 99.91 | 99.64 | 100.27 |

Calculating the amount of urao as before, we get

| | No. 5, first crop. | | | No. 6, first crop. | | |
|---|---|---|---|---|---|---|
| | Urao. | $Na_2CO_3$-$H_2O$. | Residue. | Urao. | $NaHCO_3$. | Residue. |
| $H_2O$ | 14.35 | 1.14 | .47 | 15.38 | ..... | .17 |
| $Na_2CO_3$ | 42.25 | 6.75 | ..... | 45.29 | ..... | ..... |
| $NaHCO_3$ | 33.48 | ..... | ..... | 35.89 | .30 | ..... |
| NaCl | ..... | ..... | 1.72 | ..... | ..... | 2.88 |
| | 90.08 | 7.89 | 2.19 | 96.56 | .30 | 3.05 |

| | No. 7, first crop. | | | No. 9, second crop. | | |
|---|---|---|---|---|---|---|
| | Urao. | +$NaHCO_3$. | +Residue. | Urao. | +$Na_2CO_3$-$H_2O$. | +Residue. |
| $H_2O$ | .22 | ..... | .70 | 14.00 | .91 | .50 |
| $Na_2CO_3$ | .64 | ..... | ..... | 41.24 | 5.36 | ..... |
| $NaHCO_3$ | .51 | 97.57 | ..... | 32.68 | ..... | ..... |
| NaCl | ..... | ..... | Undet. | ..... | ..... | 5.58 |
| | 1.37 | 97.57 | .70 | 87.92 | 6.27 | 6.08 |

The early products of the other solutions did not differ in physical properties from those examined, and were therefore not analyzed. The mother liquors, however, if allowed to evaporate till all the urao and most of the NaCl had been deposited, yielded crops of the monohydrated carbonate $Na_2CO_3$, $H_2O$, as was shown by analysis; but any considerable fall in the temperature of the solution caused a crystallization of the decahydrated salt.[1]

From the results before us it is evident that no such compound as the sesquicarbonate is obtained from a solution of the two carbonates by spontaneous evaporation and crystallization, and no other compound carbonate but urao was produced in any of these experiments. If there is an excess of $NaHCO_3$ present this will separate first, but the next

[1] An abstract of these results was published in a paper on "Urao," in Am. Jour. Sci., vol. 38, July, 1889, p. 59 seq. The crystals obtained as above were crystallographically examined by Mr. Edward F. Ayres, who published his results in the same number of the Journal. He shows that urao is monoclinic, but that the angles differ but slightly from those of orthorhombic forms, and quotes Zepharovich (Zeitschrift f. Kryst., vol. 13, p. 135, 1887), who obtained similar results on a urao formed accidentally by Reinitzer, whose analytical determinations agree with my own. Reinitzer gives as sp. g. 2.14, my own determination being 2.1473.

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product will be urao. As the urao crystallizes upon and intermixed with the previously separated bicarbonate, it is clear that unless the two are carefully separated an analysis of the product may give results ranging all the way from pure bicarbonate to pure urao, or ultimately the neutral carbonate. The variations in the analyses of natural soda are thus explainable, since the bottom part of a cake of such soda should generally be richer in bicarbonates than the rest. This will be still more likely if much NaCl is present in the solution, since, as shown by No. 6, $NaHCO_3$ was separated, although the proportion of $Na_2CO_3$ present was four times that required for urao. In No. 5 the proportion of $NaHCO_3$ or of NaCl is too low, as shown by the presence of $Na_2CO_3$ in the first crystallization. No. 9, which was considered as a crucial test of the possibility of the formation of the "supposed salt," gave even as its second crop only urao, the amount of $Na_2CO_3$, $H_2O$ being too small to be considered otherwise than as an impurity. The first products of No. 2 and No. 7 are $NaHCO_3$ almost pure, as was also No. 3, 1st crop, and No. 4, 1st. No. 2 differs from No. 4, as does No. 3 from No. 7, only in having one-half the quantity of NaCl; all of them deposited $NaHCO_3$, but No. 2 less than the others.

No. 1, which in amount of NaCl is midway between Nos. 5 and 6, shows more $NaHCO_3$ than No. 6, but less NaCl. In this case the amount of NaCl in the solution was not sufficient to separate $NaHCO_3$ until the solution had become sufficiently concentrated to deposit urao, when both salts crystallized together. This is indicated by No. 2, where the increase in the amount of $NaHCO_3$ had the effect of depositing a portion of it before the urao had formed.

That the presence of NaCl is not necessary for the formation of urao was proved by the following experiment. A saturated solution of chemically pure sodium carbonate was prepared, and into this pure carbonic acid was forced under pressure until a considerable amount of bicarbonate had been deposited. The solution was then filtered and put aside to evaporate spontaneously. No further separation of $NaHCO_3$ was observed, and in time a crop of acicular crystals was obtained which on analysis yielded the following results:

| | | | Urao. | $Na_2Co_3H_2O$. | Residue. |
|---|---|---|---|---|---|
| $H_2O$..... 20.14 | $H_2O$..... 16.33 | = | 15.21 | + .59 + | .53 |
| $Na_2O$.... 41.40 | $Na_2CO_3$.... 48.35 | = | 44.85 | + 3.50 | .. |
| $CO_2$..... 38.69 | $NaHCO_3$... 35.55 | = | 35.55 | .... | .. |
| 100.23 | 100.23 | | 95.61 | 4.09 | .53 |

The salt is therefore urao with a small proportion of $Na_2CO_3$, $H_2O$. The residue of water is very nearly sufficient for the dihydrated salt, but in view of what has been already shown it is more reasonable to consider it as an excess. It will be observed that no tendency to form sesquicarbonate is evinced, although it would seem that the circumstances were most favorable for its production.

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Experiment has also shown that if a moderately concentrated solution of pure $Na_2CO_3$ be exposed to the air until crystallization begins, the first crystals obtained are urao, owing to the absorption of $CO_2$ from the air during the slow evaporation. It is therefore very remarkable that the voluminous literature of soda takes such slight notice of this salt, which must have been so frequently seen by those working with soda salts.[1] Even Lunge's great work mentions urao but once, and then only as a synonym for trona, although its nature and properties would appear to give valuable hints for technical work.

As has been already seen, Wallace had a suspicion that such a compound existed, but Mondesir[2] has the credit of being the first to publish a method for its production in a pure state. After alluding to the doubts concerning the nature of "sesquicarbonate," he gives an account of his work on the mineral waters of Royat, in the course of which he established the presence of urao. In describing it he says:

> This salt is very stable in saturated solutions of NaCl probably because it is only slightly soluble even with the aid of heat, and even on boiling loses its acid carbonic acid with excessive slowness. Nevertheless a certain excess of the neutral carbonate is necessary for its preservation.

His method of preparation is to dissolve 28 parts of NaCl and 28 parts of $Na_2CO_3 . 10H_2O$ in 100 parts of water. The solution is then heated nearly to boiling and a thoroughly incorporated mixture of 8 parts $NaHCO_3$ and 28 of $Na_2CO_3 . 10H_2O$ is gradually added in small portions, the liquid being continually stirred, and the loss by evaporation being made good by addition of distilled water. As soon as the solution is complete the liquid is allowed to cool slowly, when the urao crystallizes in fine needles. He advises that the temperature of the liquid should not be permitted to go below 20°C. (68°F). The salt crystallizes in fine needles matted together, and when treated with water, is decomposed, $Na_2CO_3$ going into solution, while $NaHCO_3$ is undissolved.

To this salt, which he recognizes as being the same as Boussingault's urao, he gives the name "carbonate quatre-tiers," or "four-thirds carbonate," on account of the relation of $CO_2$ to $Na_2O$. In the sesquicarbonate we have the relation of one and one-half equivalent of $CO_2$ to one equivalent of $Na_2O$, whence its name, while in urao the relation is four-thirds of an equivalent of acid to one of base. It might, therefore, be called the "tetra-trita" or "tetrita carbonate."

Mondesir's view that the presence of NaCl and excess of $Na_2CO_3$ is of value in the formation of the salt is in harmony with my own results, though my work shows that the NaCl is not absolutely necessary, and that the aid of artificial heat can be dispensed with unless the atmospheric temperature is below 20°C. If the solution is cooled down below that point, the excess of $Na_2CO_3$ is liable to crystallize out as the decahydrated salt.

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[1] See note on p. 82 concerning Reinitzer's work.

[2] Mondesir, Paul de: Comptes Rendus, Mai 31, 1887, civ. 22, p. 1505.

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## ANALYTICAL METHODS.

The analytical methods employed in these analyses are in general well known. The salts and solutions necessarily contain only traces of other bases beside alkalies, and those were determined in the usual manner. Silica may exist in some quantity, but the amount is usually small.

$SO_3$ and Cl were determined gravimetrically and in duplicate, the results agreeing in most cases very closely. When $SO_3$ is precipitated by $BaCl_2$ in such solutions containing alkaline salts only, and these in small quantities, and care is taken that the precipitant is in slight excess only, the precipitation is both rapid and complete and the precipitate is pure, the after treatment with HCl rarely showing a loss of any consequence.

The $CO_2$ was determined by distillation, the gas being collected and weighed in a Liebig potash bulb, and the apparatus and method are fully described in "Analyses of waters of the Yellowstone National Park." Gooch and Whitfield, Bulletin No. 47, U. S. Geol. Survey, p. 15. With care and experience the results agree very closely. For the boric acid, in the water of Owen's Lake, the excellent method of Gooch[1] was followed; for the Mono and Ragtown waters the process of Stromeyer, with modifications of my own, was used; but, though giving very fair results, the process can not be compared for ease, simplicity, and accuracy with the former method.

The determination of the alkalies in such very dense waters was, at first, found to be difficult, owing to the large quantities necessarily taken. To get determinations which shall be fairly accurate when referred to a liter, portions of not less than $50cm^3$ should be taken, the water in all cases being carefully weighed. The amount of alkaline chlorides corresponding to $50cm^3$ of such waters is very large, and, when the final evaporations are being made, there is great liability to loss, owing to the formation of a salt crust on the surface of the liquid and subsequent spirting, caused by steam and ammonia vapor produced under the crust. This takes place no matter how carefully the evaporation be carried on, and many determinations were thus lost.

The use of hydrochloric acid enables us, however, to completely obviate this difficulty. The purified alkaline chlorides are to be evaporated till crystallization begins; the platinum vessel is then removed from the water bath, and an equal bulk of very pure, highly concentrated hydrochloric acid added to the solution. A copious precipitation of finely granular salts at once ensues, and, on replacing the vessel on the water bath, evaporation goes on quietly and rapidly, no salt crust is formed, and when the final heating is given, little decrepitation occurs. In this manner it is as easy to handle several grams of

[1] Gooch: Proc. Am. Acad. Sci., 1886, p. 167.

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chlorides and to obtain accurate determinations as it is when we have to deal with the far smaller quantities usual in mineral analysis.

The water in the salts was determined by means of the apparatus figured. A is a combustion tube drawn out and bent at a right angle. The platinum boat B, containing the salt, rests upon the thin sheet of asbestos paper C, used to prevent adhesion between the platinum and the heated glass. D is a roll of asbestos paper wrapped with thin platinum wire, which fits loosely in the tube and prevents back currents of air during the heating. The bent end of the combustion tube enters one limb of the U tube E, which is my own form, and differs, as the drawing shows, materially from the forms now on the market, in having an especially large bulb at the bottom. The two limbs of this tube are filled with glass beads wet with strong sulphuric acid. Sufficient acid should be put in so that the narrow tubes are filled up to the bends and the air forced to bubble through.

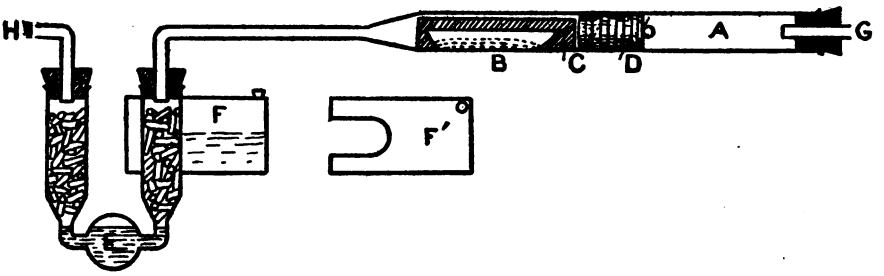


FIG. 4.—Apparatus for determination of water.

In using the apparatus the tube is thoroughly heated and then allowed to cool, a current of perfectly dried air being continually passed through it. The part of the tube where the boat is placed is protected by a semi-cylinder of sheet-iron lined with asbestos paper.

The U tube, having been weighed, is then attached to the combustion tube as shown and the air current regulated. The platinum boat which has been heated and then cooled in a desiccator, is now weighed and about one gram of the salt put into it and spread evenly along the bottom. The salt should be very finely pulverized to prevent decrepitation on heating. The boat with its contents having been weighed, it should at once be inserted into the tube and the asbestos plug D which has been highly heated and should still be hot, shoved in close behind the boat.

The tube is now heated gradually, beginning at the plug. As the water in such salts is driven out in great part at a low temperature the heating must be done cautiously and the air current watched, since, if it is too slow, water may condense in the cold part of the tube behind the plug. This regulation of the air current is the more difficult, since the acid $CO_2$ of the bicarbonate is set free simultaneously with the

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water, but upon it and the gradual heating depends the success of the operation.

The water bath F, of which $F^1$ is a top view, is now put into position, so that one limb of the U tube fits into the curved recess in the side of the bath. A small alcohol lamp keeps the bath hot, so that the water driven out of the salt may not condense in the upper part of the limb. By the use of this bath the time of the operation is much shortened.

As soon as that part of the tube containing the boat appears free from condensed water it should be highly heated until all the moisture has disappeared from the drawn-out portion. This will generally take from twenty minutes to half an hour, and when completed the water bath is removed and the apparatus allowed to cool, the air current being still kept up. As soon as the tube is cool the U tube is disconnected and the boat removed and placed in a small, well-stoppered glass tube, which has been weighed. The increase of weight of the U tube gives he amount of water in the sample, while the weight of the small tube containing the boat and calcined salt, if subtracted from the sum of the weights of the boat, the salt taken and the weighing tube shows a loss which is the water plus the acid $CO_2$ of the bicarbonate. The calcined salt which should be sintered together, but not fused, can then be used either for a determination of the residual $CO_2$ or, as is usually done, dissolved and the alkali determined by standard sulphuric acid, methyl orange being used as the indicator, the same portion being then used for the Cl determination.

Many attempts were made to collect and weigh the $CO_2$ driven off by heat, but it was found impracticable to do so without at the same time sacrificing the water determination. No matter how carefully the heat and air current are regulated, the $CO_2$ comes off too rapidly for proper absorption in the potash bulb, and if the air current is too slow, water condenses back of the plug and this determination is too low.

When no attempt is made to absorb the $CO_2$ the results are very satisfactory. In the analysis of urao "best specimen" given on page 76, we have as the mean of three closely agreeing $CO_2$ determinations 38.13 per cent., while two determinations of the alkali gave 40.28 per cent., equivalent to 28.58 per cent. of $CO_2$ required to make monocarbonate. Deducting this amount from that of the total $CO_2$ we have 9.55 per cent. as the acid $CO_2$ of the bicarbonate present. The determinations with the above described apparatus gave the following results:

| Salt taken. | Loss of boat. | $H_2O$. | Difference $=CO_2$. |
|---|---|---|---|
| 1.0040 | 29.51 | 20.12 | 9.39 |
| 1.0490 | 29.58 | 20.09 | 9.49 |
| 1.1583 | 29.49 | 20.00 | 9.49 |
| 1.0638 | 29.53 | 20.07 | 9.46 |

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We have therefore as average 9.46 per cent. $CO_2$ found, which being deducted from the calculated amount 9.55, leaves an excess of 0.09 per cent. not driven off.

In another sample of urao:

| Salt taken. | Loss of boat. | $H_2O$. | Difference $=CO_2$. | $CO_2$ in residue. | Sum of $CO_2$. |
|---|---|---|---|---|---|
| 1.1801 | 29.27 | 19.80 | 9.47 | 28.69 | 38.16 |
| 1.2297 | 29.35 | 19.83 | 9.52 | 28.64 | 38.16 |
| 1.2066 | 29.39 | 19.85 | 9.54 | 28.49 | 38.03 |
| 1.0880 | 29.26 | 19.80 | 9.46 | 28.67 | 38.13 |
| 1.1761 | 29.32 | 19.82 | 9.50 | 28.62 | 38.12 |

Two determinations of total $CO_2$ gave 38.17 and 38.22 per cent.—average 38.19. Two determinations of alkali gave 40.19 and 40.22 per cent. $Na_2O$, average 40.20—equivalent to 28.53 per cent. $CO_2$. Hence, as 28.62 per cent. $CO_2$ was found in the residue and only 28.53 was necessary for the combination $Na_2CO_3$, we have 28.62—28.53=0.09 per cent. $CO_2$ not driven off.

In a sample of Trommsdorff's C. P. sodium bicarbonate there was found:

| Salt taken. | Loss of boat. | $H_2O$. | Difference $=CO_2$. | $CO_2$ in residue. | Sum of $CO_2$. |
|---|---|---|---|---|---|
| 1.4265 | 36.68 | 10.91 | 25.77 | ..... | ..... |
| 1.5995 | 36.81 | 10.90 | 25.91 | ..... | ..... |
| 1.3200 | 36.71 | 10.91 | 25.80 | 26.25 | 52.05 |
| 1.3723 | 36.73 | 10.98 | 25.75 | 26.37 | 52.12 |
| 1.4296 | 36.73 | 10.92 | 25.81 | 26.31 | 52.09 |

Two determinations of total $CO_2$ gave 52.06 and 51.90, average 51.98 per cent. Two determinations of alkali gave 36.86 and 36.90, average 36.88 per cent. $Na_2O$, equivalent to 26.17 per cent. $CO_2$. Subtracting 26.17 from 26.31, the average amount in the residue, we have 0.14 per cent. $CO_2$ not expelled by heating to the sintering point.

Comparing these amounts of excess of $CO_2$ retained by the residues of the ignition, we find the following relation:

| Sample. | Number of determinations. | Average weight taken. | Average excess, per cent. | Relation of excess to weight. |
|---|---|---|---|---|
| Urao, No. 1..... | 3 | 1.0638 | 0.09 | 0.084 |
| Urao, No. 2..... | 4 | 1.1761 | 0.09 | 0.077 |
| Bicarbonate..... | 4 | 1.4296 | 0.14 | 0.091 |
| Average..... | ..... | ..... | ..... | 0.084 |

Hence we may say that if sodium bicarbonate, or a salt containing a large proportion of it, is heated till it sinters without fusing, and is kept at that temperature for one hour, it still retains $CO_2$ in excess of the amount required to form monocarbonate with the alkali present,

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and that for quantities of from 1 to 1.5 grams this excess may be considered as one-tenth of one per cent. of the weight of the salt taken.

For an analysis of sodium bicarbonate by means of this method it is therefore sufficient to determine the loss by ignition, the $H_2O$, and the alkali in the ignited residue to obtain the total amount of $CO_2$ in the sample, adding in an amount of $CO_2$ equal to 0.10 per cent. of the weight of the salt taken. This method for the analysis of bicarbonate or "baking soda" is much more rapid, far easier and quite as accurate as the distillation process, and may prove of value for technical purposes.

## ORIGIN OF NATURAL SODA.

We have seen that this material occurs in many widely separated localities, which have, perhaps, but one characteristic in common, namely, a very dry climate. The presence of volcanic rocks belonging to late geologic periods, though proved in many instances, has not as yet been shown for a few of them, such as Hungary and Egypt.

Dryness of climate has no other effect, probably, than to retain within a given region its product of natural soda, which would otherwise be continually carried off to the sea through natural drainage, though the consequent inclusion of the drainage in closed basins may be necessary to permit of certain chemical after-reactions.

In an arid region like our Great Basin, but a small portion of the total rainfall reaches the ocean. Rivers of considerable magnitude terminate in "sinks" or lakes without outlet. Such lakes are naturally impregnated with salts, since each drop of inflow brings its quota, and the only loss that such a basin suffers is by evaporation, which carries off no solid matter.

Unless chemical changes occur in the lake itself, such a body of water represents a simple concentration of its inflowing streams, and if we find it to contain any given salt, it is evident that this salt has either been brought as such into the basin, or is a product of chemical after-reactions among the constituents of the lake water. If the salt has been brought as such it is a product of rock or soil decomposition, and is in solution as a result of a leaching process, whether the water came from a deep-seated spring or is a mere surface drainage.

The existence of springs carrying sodium carbonate is well-known, since many of them have a world-wide reputation for their medicinal qualities. Although most of them are weak solutions, a comparison of their compositions with those of the waters described in this paper will show that they would by sufficient evaporation yield a very pure natural soda. The sodium carbonate in such springs is produced by decomposition of the alkali-bearing rocks through which the water flows, and this decomposition is brought about by the combined action of air and moisture, aided in many instances by heat and pressure.

The air absorbed by water contains a much larger proportion of oxy-

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gen and carbonic acid than the normal atmosphere, the composition of which may be taken as

| | |
|---|---|
| Oxygen | 20.9512 |
| Nitrogen | 79.0073 |
| Carbonic acid | 0.0415 |

while the air absorbed by water at 15° C. (60° F.) contains, according to Bunsen,

| | |
|---|---|
| Oxygen | 34.12 |
| Nitrogen | 63.62 |
| Carbonic acid | 2.26 |

The alkali-bearing minerals are generally silicates, having for bases ferrous or ferric oxide, alumina, lime, magnesia, soda and potash in varying proportions according to the character of the mineral. Thus orthoclase feldspar is composed, essentially, of silica, alumina and potash; albite, of silica, alumina and soda; anorthite, of silica, alumina and lime, but they are rarely found pure and there exist many intermediate steps, so that orthoclase usually contains soda and lime in varying proportions, while magnesia and ferric oxide replace in part lime and alumina respectively.

By the action of water, containing carbonic acid, upon such minerals, the alkalies and alkaline earths are converted into carbonates and dissolve in the carbonated water. Hence they are leached out of the residue, which is rendered the more porous through the decomposition, and if the water so charged does not on its way to the surface meet with sulphates or chlorides of other metals which, by double decomposition, would produce alkaline sulphates or chlorides and non-alkaline carbonates, the alkaline carbonates make their appearance as constituents of a mineral spring. In such springs the salts of sodium are usually in much greater proportion than those of potassium, not only because the soda minerals are, in general, more easily decomposable, but also because soils have a strong tendency to take up and retain the potash salts from water percolating through them while readily giving up their contents of soda salts.

If the waters of such springs flow into basins without outlet and the rate of evaporation equals the inflow, a concentrated solution gradually results, and if the inflow be interrupted, we shall in time have a dry basin in which the salts have deposited as a crystallized mass. It is evident that if the geological character of a country is favorable to the production of such alkaline springs, the dryness of the climate or the excess of evaporation over rainfall determines the degree of concentration of the contents of their basins, the number of which is dependent on the topography, and the consequent productiveness of the region in natural soda.

We have so far considered original formation and simple evaporation only. There are, however, a number of instances in which the alkali appears to be the result of more complicated chemical reactions. We have already seen the views of Szabo and Moser as to the mode of

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origin of the Hungarian soda, in which the carbonate of lime is supposed to play a part. Lunge[1] refers to the fact that from a damp mixture of common salt and lime soda effloresces in the air after several weeks' time, and also states that "from a solution of common salt a solution of bicarbonate of lime precipitates sodium bicarbonate; apparently this reaction explains the formation of soda efflorescence in soils containing common salt." If the more soluble magnesium bicarbonate be substituted for the calcium salt we have Weldon's process for soda making.

It may therefore be said that if common salt and limestone or dolomite are present together in a soil, subject to the action of air, moisture and climate, all the conditions for the production of natural soda are at hand, and it is thus that the origin of the soda of Egypt may be explained. Russegger's description of this locality has already been cited. After ascribing the formation of the sodium carbonate to reactions occurring between the $CaCO_3$ $Na_2SO_4$ and NaCl, by which $Na_2CO_3$ $CaCl_2$ and $CaSO_4$ are formed, he says:

The first two ($Na_2CO_3$ and $CaCl_2$) dissolve in the water of the lakes together with the undecomposed $Na_2SO_4$ and NaCl, and thus we have a lye containing NaCl, $Na_2SO_4$, $Na_2Co_3$ and $CaCl_2$.

A very slight knowledge of chemistry tells us that $Na_2CO_3$ and $CaCl_2$ cannot exist together in solution, since $CaCO_3$ must be precipitated at once, NaCl remaining in solution; so Karsten (loc. cit.) adds the following note:

This transformation of the salts is undoubtedly a consequence of the oxydation of the pyrites in the clay to sulphates, followed by a double decomposition of these sulphates by the NaCl and $CaCO_3$ in the clay. The sodium and calcium sulphates so formed are then reduced to sodium and calcium sulphides and these are decomposed by means of NaCl and $CaCO_3$. The process must, therefore, be considered as very complicated and as demanding not only length of time but also a co-operation of special conditions, precisely as they occur in the Egyptian lakes. The organic matter here present may well be considered as the sole and only cause whereby the sulphates are reduced to sulphides, these being changed then to carbonates.

Abich, in his description of the Armenian localities, already given in part, ascribes the formation of the sodium carbonate there found more particularly to the action of plant life. The salt grasses and other plants which grow in that region yield an ash rich in soda salts, those from Armenia being richer in $Na_2CO_3$, while those from the Steppes contain a larger proportion of $Na_2SO_4$. The soil of the Steppes contains much $Na_2SO_4$, but is poor in NaCl, precisely the reverse of the soil of Armenia; hence the conclusion that the $Na_2CO_3$ is formed by the action of the plant on NaCl, comparable with the formation of potassium carbonate, which usually predominates in the ash of land plants. The growth, death and decomposition of successive crops of such plants would, under this view, continually increase the amount of sodium carbonate in the soil without taking into consideration the amount pro-

[1] Lunge: Sulph. Acid and Alkali, Vol. 2, p. 310.

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duced by direct weathering of the eruptive rocks so abundant in that region.

We have already seen that the deposits of Wyoming consist in great part of sulphates and chlorides, though occasionally the percentage of carbonate becomes sufficiently large to be of importance. This is also true of the Lake Bonneville region as described by King in the 40th Parallel report, already frequently quoted. In vol. 1, page 500, he shows that the salts are mainly chlorides and sulphates, the former largely predominating, while carbonates are generally absent. The water of the Great Salt Lake may therefore be taken as typical for the region. As one proceeds westwardly the occurrences of alkaline carbonates are more frequent and the percentage of this salt greater until we reach the Lahontan region of western Nevada, where the proportion of alkaline carbonate is usually greater than that of sulphate.

The cause of this chemical change in the nature of the salts, though much discussed, is not yet ascertained. So far as we know, there is no such difference between the rocks of the eastern and the western portion of the Great Basin as would account for this increase of the carbonate. In both sections the eruptive rocks are of similar character, and, by their decomposition, should yield the same products. It is possible that the fact that volcanic action has persisted to a much later date on the western border than on the eastern side may have some influence. Hot springs are much more common along the foot of the Sierra Nevada, and some of the volcanoes have been active at a comparatively recent date. The enormous volume and high temperatures of the heated waters of the Comstock Lode may also be considered as showing a probably greater activity in rock decomposition but not, necessarily, a difference in character of product.

Once formed through rock decomposition, a solution containing sodium chloride, sulphate and carbonate would afterwards lose none of its carbonate unless soluble earthy salts were added to it; on the contrary, when such a water reaches an enclosed basin, the proportion of sodium carbonate tends, following the views of Karsten, to increase through the reduction of the sulphate by organic matter and the subsequent action of the atmospheric carbonic acid on the sulphide; a reaction which requires a period of comparative rest, which such a basin affords. It has been already stated that the waters of springs carrying alkaline carbonate may lose the whole of it on the way to the surface by passing through formations containing non-alkaline soluble salts, such as gypsum, calcium chloride or magnesium salts, resulting in the formation of calcium or magnesium carbonate and alkaline sulphate or chloride. The same reaction would occur if the surface water percolates through soils containing these salts, or if water containing them be added to the streams or basins.

It is probable that an alkaline lake or the dry deposit resulting from its desiccation is in all cases the result of both primary rock decomposition and subsequent chemical change. The latter usually appears to be the

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subordinate agent, but still occupies a definite position, and in this connection the results of the examination of certain seepage waters from the shore of Owen's Lake are interesting. The analysis of the water of this lake shows that sulphides are absent, the most careful tests showing merely a doubtful trace. On page 76, a urao was described as having been produced from seepage water collected in a vat dug on the beach and for practical reasons it was desirable to study the nature of the seepage. To this end, small pits were dug in a line extending from the vat to a point much above the highest recent water mark of the lake. From each of these pits, beginning with the one most distant from the lake, a sample of the seepage water was taken and the specific gravity tested, as follows:

| Sample. | Temperature. | Specific gravity. | Remarks. |
|---|---|---|---|
| | ° C. | | |
| No. 1 | 32 | 1.005 | |
| No. 2 | 31 | 1.035 | |
| No. 3 | 31 | 1.050 | |
| No. 4 | 31 | 1.050 | |
| No. 5 | 32 | 1.062 | Analyzed. |
| No. 6 | 32 | 1.090 | |
| No. 7 | 32 | 1.108 | |
| No. 8 | 31 | 1.085 | Analyzed. |
| No. 9 near vat | 31 | 1.063 | Do. |
| Lake water | 25 | 1.062 | |

The soil of these pits showed no variety; in each case it was found that the surface sand was underlaid by a dark grey material similar to a very sandy clay and closely resembling the "volcanic ash" common in this section, and which it is considered to be. A sample was taken from pit No. 9 and analysed as follows, having been partially dried, when it became pulverulent and of a pale yellowish grey color.

| | | | |
|---|---|---|---|
| $H_2O$ at 110° | .65 | $H_2O$ | 3.15 |
| $H_2O$ at red heat | 2.50 | *Soluble part.* | |
| $CO_2$ in soluble part | .87 | NaCl | 1.45 | |
| $CO_2$ in insoluble part | 6.35 | $Na_2SO_4$ | .80 | |
| $SO_3$ | .45 | $Na_2CO_3$ | 2.09 | 4.34 |
| Cl | .88 | *Insoluble part.* | | |
| $SiO_2$ | 55.81 | $CaCO_3$ | | 14.44 |
| $TiO_2$ | .80 | $SiO_2$ | 55.81 | |
| $P_2O_5$ | .27 | $TiO_2$ | .80 | |
| $Al_2O_3$ | 10.07 | $P_2O_5$ | .27 | |
| $Fe_2O_3$ | 3.43 | $Al_2O_3$ | 10.07 | |
| FeO | .67 | $Fe_2O_3$ | 3.43 | |
| MnO | .23 | FeO | .67 | |
| CaO | 9.14 | MnO | .23 | |
| MgO | 2.22 | CaO | 1.05 | |
| $K_2O$ | 2.98 | MgO | 2.22 | |
| $Na_2O$ | 3.09 | $K_2O$ | 2.98 | |
| | 100.41 | $Na_2O$ | .75 | 78.28 |
| O=Cl | .20 | | | 100.21 |
| | 100.21 | | | |

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*Analyses of the samples of seepage water.*

| Specific gravity and temperature. | Pit No. 5. | | Pit No. 8. | | Pit No. 9. | |
|---|---|---|---|---|---|---|
| | 1.06872 (22.5° C.) | | 1.0881 (24.1° C.) | | 1.07308 (21° C.) | |
| In 1 liter. | Weight. | Per cent. | Weight. | Per cent. | Weight. | Per cent. |
| Cl | 24.316 | 27.92 | 29.412 | 25.87 | 23.808 | 25.84 |
| $SO_3$ | 6.092 | 6.99 | 8.664 | 7.62 | 4.936 | 5.36 |
| O | 1.216 | 1.40 | 1.732 | 1.52 | .988 | 1.08 |
| S (sulphur) | trace... | ..... | .120 | .11 | .161 | .17 |
| $CO_2$ | 15.172 | 17.42 | 21.100 | 18.56 | 19.320 | 20.97 |
| O | 5.516 | 6.33 | 7.672 | 6.75 | 7.024 | 7.63 |
| K | 2.352 | 2.70 | 2.612 | 2.30 | 2.020 | 2.20 |
| Na | 32.064 | 36.82 | 41.896 | 36.85 | 33.426 | 36.24 |
| $SiO_2$ | 0.296 | .34 | .316 | .28 | .260 | .29 |
| $Al_2O_3$ | undet .. | ..... | .008 | .007 | .008 | .01 |
| Ca | undet .. | ..... | .020 | .02 | .014 | .015 |
| Mg | undet .. | ..... | .009 | .008 | undet .. | ..... |
| $B_2O_3$ | present | ..... | undet .. | ..... | undet .. | ..... |
| H | .072 | .08 | .120 | .105 | .176 | .20 |
| | 87.096 | 100.00 | 113.681 | 100.00 | 92.142 | 100.00 |

*Hypothetical combination.*

| | Weight. | Per cent. | Weight. | Per cent. | Weight. | Per cent. |
|---|---|---|---|---|---|---|
| $SiO_2$ | .296 | .34 | .316 | .28 | .260 | .30 |
| $Al_2O_3$ | ..... | ..... | .008 | } .08 | .008 | } .04 |
| $CaCO_3$ | ..... | ..... | .044 | | .032 | |
| $MgCO_3$ | ..... | ..... | .033 | | ..... | |
| KCl | 4.487 | 5.15 | 4.991 | 4.39 | 3.864 | 4.19 |
| NaCl | 36.549 | 41.96 | 44.545 | 39.18 | 36.199 | 39.28 |
| $Na_2SO_4$ | 10.812 | 12.41 | 15.376 | 13.52 | 8.757 | 9.49 |
| $Na_2S$ | trace. | ..... | .292 | .26 | .392 | .43 |
| $Na_2CO_3$ | 28.876 | 33.17 | 37.884 | 33.33 | 27.817 | 30.19 |
| $NaHCO_3$ | 6.076 | 6.97 | 10.192 | 8.96 | 14.813 | 16.08 |
| | 87.096 | 100.00 | 113.681 | 100.00 | 92.142 | 100.00 |

In comparing these analyses we must remember that the water here examined is not the lake water, but the drainage from fresh springs along the base of the Inyo Range. As the water passes through the volcanic ash it gradually becomes laden with the salts produced by the decomposition of the soil as shown by No. 5. At this point the amount of sulphur or sulphuretted hydrogen present, though small, was unmistakable, showing that a reduction of sulphates had begun. In No. 8 the percentage of chlorides had diminished, and that of bicarbonate had increased, while the percentage of sulphates was somewhat larger, although sulphides were present in weighable quantities. No. 9 is very regular in its results if compared with No. 5. The chloride and sulphates have suffered a considerable decrease, while sulphides are in

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as large a proportion as we should expect, considering that they would be destroyed at once if in solution with bicarbonates. The sodium monocarbonate is apparently less in amount than in the first analysis, but we observe a great increase in bicarbonate, so the percentage of alkali in the last analysis shows a large gain over the first one. As the distance from one pit to the next was not more than a hundred yards, this process of alkali production is really quite a rapid one, and the solutions obtained are stronger and of better quality for practical purposes than the mass of the lake water.

## CAUSE OF THE RED COLOR OF CONCENTRATED ALKALINE BRINES AND OF THE SALTS OBTAINED FROM THEM.

The red color which brines, particularly those of an alkaline character, are apt to assume when concentrated, and which is frequently taken up by the deposited salts, has often been noticed. The cause of this color has been studied by Payen,[1] who finds that it is due to the presence of the small crustacean, Artemia salina, Leach (Cancer salinus, Linn.), known in the West as the "alkali shrimp." In his experiments carried on at the Salines of Marignano, he found that the brine in concentrating to 15° B. becomes entirely clear and colorless, continuing until it reaches 20° B., at which point large numbers of small animals, grey or greenish grey in color, are observed swimming in the liquid. As the brine concentrates to nearly 25° B. all of these little crustaceans die, turn red, come to the surface and form a red foam, which is composed of the fragments of their bodies and gives a peculiar odor. Experiments showed that if the concentration of the brine did not exceed 20° B. the animals were healthy, provided that they had air and that the solution did not become acid. If the solution became acid, the animals became sluggish and moribund, but were revived as soon as the solution was rendered alkaline.

The same may be said of the brine at 15° B. For a short time the animals were very lively, but on the fourth day became sluggish. Rendering the solution alkaline revived them to some degree, and on reducing a portion of the solution to 3° B. the crustacea in it remained alive and vigorous up to the time when the paper was written.

Those in the solution at 20° B. were lively during two days, then began to die, and all were dead on the third day. In fresh water all died within four days. In solutions at 23° B. all died within twenty-four hours, having become much redder than in the weaker solutions, and settled on the bottom as a brown sediment. These experiments show that a certain degree of concentration and a certain degree of alkalinity are necessary for the life of these animals, and that greater concentration causes death and the consequent red coloration.

The letter of Audouin accompanying the paper gives the observa-

[1] Payen: Ann. de Chimie, pt. 2, vol. 65, pp. 156–169.

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tions of Schlosser made at Lymington, England, in October, 1755. The latter describes these animals as follows:

The body is merely a tube, cylindrical or vermicular in form, very slender, and about one-third of an inch in length. At one end of this tube are two antennæ, very delicate and short, and two black eyes, round and elevated; between these eyes is a black spot, which may be a third eye. A curved mouth is placed under the eyes. The body is provided with 21 pairs of natatory legs, the longest being in the center of the body, the others becoming shorter as they approach the head and tail. The posterior part is bare, the anus being at the extremity. The females have posterior to the last pair of legs a sac, usually three or four times the diameter of the tube, containing eggs; the males have, anterior to the first pair of legs, two long flattened arms, with these they seize the females, and while attached to them appear to squeeze out several eggs. The animals thus attached swim together for some time.

D'Arcet observed the red color of the Egyptian lakes, but finding only a few artemia, did not consider that the color was due to them. In the West the artemia are very plentiful and the red color is very usual, though generally ascribed to some property of the salt grasses. It is probable that the opinion of Payen is the correct explanation.

## LEACHING OF ALKALINE SOILS AND CLAYS.

A chemical examination of a soil always includes a leaching with water and the analysis of the soluble portion. This is especially necessary in the case of samples from alkaline terranes, where the percentage of soluble salts is often large, and unless these can be extracted without alteration, no correct conclusion can be drawn as to the character and agricultural possibilities of the soil. In such regions crops can seldom be grown without irrigation, which not only supplies the plants with the necessary moisture, but also improves the land by leaching out the surplus salts, which may, under exceptional circumstances, be profitably recovered from the leachings.

The extraction of the soluble constituents from such soils and clays is often difficult, because when the sample is mixed with water subsidence is exceedingly slow, and filtration, if at all practicable, yields a very turbid solution. Having to examine a number of such samples, experiments were made to find out the simplest method of securing a clear aqueous solution containing only the naturally soluble salts. The presistent turbidity seems to be in some way connected with the alkalinity of the solution, since if this is rendered slightly acid, subsidence is rapid and a clear liquid is easily obtained. By acidifying, however, all the carbonates are decomposed and the resulting solution tells us nothing concerning the character of the original material.

It is well known that sea water precipitates the finely divided suspended material from inflowing river waters, and experiments based on this observation have shown that the addition of a small proportion of pure sodium chloride is all that is needed to obtain a clear and unaltered solution. Three samples of so-called "clays" from Owen's Lake have been especially examined for this purpose.

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In making vats at the soda works at this place it was found that some of them could not be rendered water tight without great expense, and the reason of this was sought. Sample No. 1 represents this class of ground, while the combination of Nos. 2 and 3 is "good ground," holding water without difficulty. If the samples are dried the difference is strongly marked, No. 1 becoming very friable, while the others are as tenacious as a brick clay of inferior quality. If the dried samples are mixed with a little water all become pasty, but if much water is added the emulsion of No. 1 subsides rapidly, a few hours being amply sufficient to give a clear supernatant liquid, which can be poured off without disturbing the compact underlying sediment. Under like conditions Nos. 2 and 3 remain turbid, and after the lapse of thirty days not more than one-tenth of the supernatant liquid was even approximately clear. By the addition of a sufficient amount of common salt the subsidence was rendered as rapid and as complete as in No. 1, and the sediments can be washed by decantation. For the determination of chlorine, dilute nitric acid is added till the solution becomes acid, producing the same effect as the addition of common salt.

No. 1 is from the "upper works" at Keeler, Owen's Lake. It is covered by the surface sand, is yellowish grey in color and, as stated, friable. No. 2 is "sandy clay" from the "central works." This is immediately under the surface sand, is about 12 to 18 inches thick, and is said to be the best for vat-making; underlying this is the "blue clay," No. 3, of undetermined depth and also very good. Analysis gave the following results:

| | No. 1. | No. 2. | No. 3. |
|---|---|---|---|
| $H_2O$ at 120° | 4.02 | 1.41 | 2.05 |
| $H_2O$ at red heat | 1.18 | 2.73 | 2.40 |
| $SiO_2$ | 45.83 | 53.24 | 54.92 |
| $TiO_2$ | .30 | .25 | .30 |
| $Al_2O_3$ | 8.05 | 10.84 | 11.25 |
| $Fe_2O_3$ | 2.77 | 2.59 | 2.77 |
| FeO | .43 | .77 | .94 |
| MnO | .12 | .10 | .08 |
| CaO | 4.88 | 9.18 | 8.76 |
| MgO | 1.23 | 5.82 | 4.91 |
| $K_2O$ | 2.86 | 2.64 | 2.77 |
| $Na_2O$ | 14.21 | 2.06 | 2.10 |
| $SO_3$ | 1.85 | .08 | trace. |
| Cl | 7.33 | .05 | trace. |
| $CO_2$ | 6.44 | 8.75 | 7.24 |
| | 101.50 | 100.51 | 100.49 |
| Deduct | 1.65 | .01 | .49 |
| | 99.85 | 100.50 | 100.00 |

| | No. 1. | No. 2. | No. 3. |
|---|---|---|---|
| Water | 5.08 | 4.14 | 4.45 |
| Soluble part | 24.80 | 1.26 | 1.41 |
| $CaCO_3$ | 6.18 | 19.07 | 15.34 |
| Insoluble | 63.79 | 76.03 | 79.29 |
| | 99.85 | 100.50 | 100.49 |

*Composition of soluble part.*

| Soluble. | No. 1. | No. 2. | No. 3. |
|---|---|---|---|
| KCl | 4.18 | ..... | ..... |
| NaCl | 11.15 | .09 | ..... |
| $Na_2SO_4$ | 3.30 | .14 | ..... |
| $Na_2CO_3$ | 7.50 | .87 | 1.18 |
| $NaHCO_3$ | 1.17 | ..... | ..... |
| $SiO_2$ | .39 | .16 | .23 |
| $Al_2O_3$ | .11 | ..... | ..... |
| . | 24.80 | 1.26 | 1.41 |



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No. 1 is evidently in great part sand, made up of quartz and small grains of eruptive rocks, and contains but little real clay. Hence it absorbs large quantities of soluble salts, but parts with them readily on leaching, leaving a porous residue, which, on account of its granular condition, subsides rapidly when mixed with water. Nos. 2 and 3 contain only small quantities of soluble salts, but chlorides are practically absent, and the residues containing considerable quantities of carbonate of lime may be viewed as marls.

The clarification by the use of NaCl must be considered as a physical phenomenon since, so far as our present knowledge extends, no chemical change is supposable under the conditions. In each of the following experiments, begun September 11, 1888, the air dried material was weighed out and put into a cylinder containing the given amount of salt dissolved in 50cm³ of water. The cylinder was then corked, shaken vigorously and allowed to stand without further disturbance.

Exp. A: 10 grams clay No. 2 (sandy clay), no NaCl. Subsidence very slow. Nov. 28. Height of column 85mm, height of sediment 47mm, supernatant liquid slightly turbid.

A¼: 10 grams No. 2, 0.025 gramme NaCl. Subsidence much more rapid, having been, apparently, completed about Oct. 1st. On Nov. 28, height of column 85mm, sediment 33mm.

A½: 10 grams No. 2, 0.05 NaCl. Subsidence complete within forty-eight hours. Column 92mm, sediment 33mm, liquid clear and line of demarkation between sediment and liquid sharply defined. A1 and A2, containing 0.1 and 0.2 grams NaCl respectively, showed complete subsidence within 24 hours.

Series B: 10 grams No. 3 (blue clay) taken.

B: No NaCl. Nov. 28. Column 86mm, of which about 5mm could be called clear, the next 10mm, though translucent, was turbid, the rest opaque.

B¼: 0.025 grams NaCl. Nov. 28, column 88mm, sediment 50mm, demarcation fair.

B½: 0.05 grams NaCl. Nov. 28, column 81mm. Sediment 44mm, demarcation definite, solution clear.

B1: 0.1 gram NaCl. Nov. 28, column 84mm. Sediment 28mm. Sedimentation complete within a week.

B2: 0.2 grams NaCl. Nov. 28, column 87mm, sediment 28mm. Subsidence complete within 48 hours.

Two portions of each clay of 5 grams each with 0.025 and 0.05 gram NaCl, respectively, showed a rate of subsidence much more rapid than that of the corresponding 10 gram portions, and this rate seems to depend upon the salinity of the solution. The further investigation of this subject involves complicated problems in physics, and for practical purposes it is sufficient to know that by the use of small quantities of NaCl the soluble portion of such clays can be easily and completely extracted.

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## CONCLUSIONS.

The conclusions arrived at in the course of this work may be briefly summarized as follows:

First. Natural soda is formed partly by direct decomposition of rocks through the action of air and water, aided at times by heat and pressure, and partly by subsequent decompositions occurring either in soils or in closed basins. These reactions, especially those of the latter class, are much influenced by the action of organic matter, which not only reduces sulphates, but also, in the form of certain organic acids, has been found to be a powerful reagent in rock decomposition.

Second. Natural soda is, essentially, a definite compound of sodium monocarbonate and bicarbonate, and the other accompanying salts are to be considered only as impurities. The proportion of the two carbonates forming this compound is one molecule of each. Any excess of either carbonate above this ratio is considered to be merely accidental, and the existence of the so-called sesquicarbonate or combination of one molecule of monocarbonate with two molecules of bicarbonate is believed to be very doubtful; at present, the strongest proof of its existence is derived from certain crystallographic determinations.

Third. The mineral urao is the pure form of natural soda, and this compound, having a relation of four-thirds of a molecule of $CO_2$ to one molecule of $Na_2O$, may be called the "tetra-trita" or "tetrita" carbonate. The sodium carbonates are therefore considered to be but three in number, namely: monocarbonate, tetrita carbonate and bicarbonate.

Fourth. The nature and properties of urao render it the most suitable form in which the natural sodium carbonates can be separated from accompanying salts. Hence any technical method devised for the manufacture of commercial soda from the natural material should be based on the formation and separation of this compound. The method described as being employed at Owen's Lake is, as far as it goes, simple and good, but the yield is not large, when the extent of the plant is considered. Owing to the small proportion of bicarbonate present in the original water, the crop is smaller than could be obtained if the amount of bicarbonate could be increased. Whether this can be economically done can be answered by practical experience only, but the following suggestions may be of value.

As the first step in the purification of a natural soda, it must be dissolved, and the solution should be clear. If such a solution be analyzed it will be found, in most cases, that the proportion of bicarbonate present is insufficient to give the largest practicable yield of urao. The amount of carbonate in the first crop depends upon the amount of bicarbonate in the solution, as this separates first and in separating takes with it a proportionate amount of monocarbonate. We have already seen that a soda ash of very good quality can be made at Owen's

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Lake, but the yield under present conditions must be small in proportion to the amount of solution used. If the percentage of bicarbonate could be economically increased, the first crop should be much larger without detriment to its purity, and the increase may be effected either by the direct addition of bicarbonate or by its formation in the solution by causing the latter to absorb carbonic acid under pressure.

If the direct addition of bicarbonate is preferred, advantage may be taken of the fact noticed by Mondesir and others, that if urao is treated with an amount of water insufficient for its complete solution, it is decomposed, $Na_2CO_3$ going into solution, while $NaHCO_3$ is left behind. Heat increases the rapidity of the decomposition, but the temperature of the solution should not exceed 37.5° C. (100° F.). The $NaHCO_3$ thus obtained can then be dissolved in the raw solution of the natural soda, which for this purpose must not be too concentrated and, as the bicarbonate dissolves slowly, agitation of the salt with the liquid will hasten this stage of the process.

The solution of $Na_2CO_3$ obtained by this treatment of a portion of the urao may be utilized by converting it into bicarbonate, using, for this purpose, the carbonic acid given off during the calcining of the soda ash. The proper form of furnace for calcining such material is a continuously working muffle, in which the soda is mechanically fed, stirred and delivered, while the $CO_2$ is obtained in a pure condition and, when cooled, can be introduced at once into the solution of $Na_2CO_3$. For rapid absorption a pressure of about 25 to 30 pounds to the square inch is advisable, hence a pump must be used and the absorbing vessels should be made of light boiler iron. The absorption should not exceed the point at which bicarbonate begins to precipitate, and if the absorbing vessels are properly arranged in a series the carbonating will be a continuous operation and the plant required for quite extensive works will be found to be much smaller than would be supposed. The carbonated solution can be added directly to the raw solution.

If the formation of bicarbonate in the raw solution is preferred, a portion of this may be thoroughly carbonated and then added to the rest. This method has some advantages over the first one, but would probably require a somewhat larger carbonating plant for works of an equal capacity.

While the summer temperature is usually sufficiently high for the proper production of urao, the season is short, under the most favorable circumstances, and the output of works depending entirely upon natural heat correspondingly small. On the other hand, the temperature of the solutions should not be allowed to exceed 100° F. If it be possible to maintain the solution at this temperature during the crystallizing stage, in an economical manner, a great gain would be made, as the works could be run throughout the year, there being, usually, but little difficulty in obtaining and storing up an ample supply of concentrated raw solution. In this direction there is an extensive field for the exercise

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of educated ingenuity in the utilization of the waste heat of the calcining furnaces, as also in the economical application of heat derived from fuel burned for this purpose only. The description of the salt works at Pomeroy, Ohio, given in my paper on salt-making processes, in the Seventh Annual Report of the U. S. Geological Survey, shows a most ingenious and exceedingly close utilization of heat derived from fuel of very poor quality, and may give many hints to those desiring to work in this direction.

The utilization of the mother liquor of the first crop is a problem which can only be solved by the growth of this industry. Doubtless in time something can be done with the vast quantities of chlorides and sulphates which are waste products, but their value is too small to give much hope for their utilization under present conditions. The industry is in a preparatory stage only, but will surely become of great importance in the future; the present consumption of sodium carbonate in this country is probably not less than 250,000 tons and is increasing, and a large part of this amount could be supplied by the Great Basin if its resources were utilized. If those who may hereafter take up and prosecute this branch of chemical industry shall find the information given in these pages of value to them, the purpose of this paper will have been realized.

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## ANALYSES OF SIX NEW METEORITES.

By J. Edward Whitfield.

*The Rockwood Meteorite.*—This meteorite was found about the middle of March, 1887, by Mr. Elihu Humbree on the range of the Crab Orchard Mountains, in Tennessee. The field in which it was picked up is now owned by Mr. W. B. Lenoir, and is situated 8½ miles west from Rockwood, in Cumberland county. The material for analysis was received from Messrs. Ward and Howell, of Rochester, N. Y., the present owners of the meteorite, to whom I am indebted for the privilege of description.

Fig. 5.—The Rockwood Meteorite.

There were three pieces found, the smallest measuring 10cm × 8cm × 6cm, and weighing 1.65 kilos; the next larger, measuring 20cm × 16.4cm × 6.5cm, and weighing 2.64 kilos; and the largest, an irregular egg-shaped mass, a little flattened on one side, measuring 38cm × 25.3cm × 21.5cm, with a weight of about 38.5 kilos and specific gravity of 4.240. An idea of the appearance of this piece can be had from the foregoing cut, which is from a photograph reduced to $\frac{1}{6}$ natural size. The mass is quite brittle, very hard to saw, but easily broken by hammering. Cut slices show many irregularly shaped stony fragments with some nodules, the largest seen being about 1cm on the surface diameter. In the larger slices the stony part is so broken as to give the polished surface a brecciated appearance.

In analysis, the metallic portion was freed from the mineral part by crushing to rather fine particles and separating by the aid of a magnet.



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This was again treated in the same manner, and the resulting metal washed with alcohol and quickly dried; by this method it was found possible to free the metal from all but the merest trace of stony substance.

The metallic portion proved to be an alloy, rich in nickel, as is shown by the following figures:

| | Per cent. |
|---|---|
| Fe | 87.59 |
| Ni | 12.09 |
| Co | trace. |
| Cu | trace. |
| P | none. |
| S | none. |
| | 99.68 |

The metallic grains seem to be quite evenly distributed through the mass. In but one instance does a nodule appear to have attained a size larger than that of a pea, and on the section of this nodule we were able to obtain the Widmannstätten figure by etching. Cut No. 2 shows the polished slice containing the nodule of natural size:

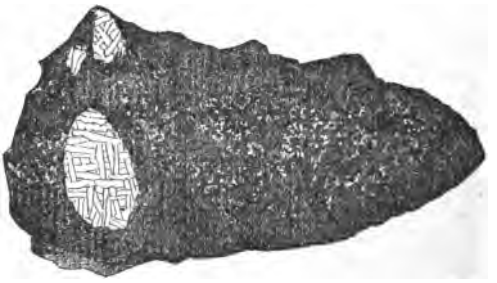

FIG. 6.—Section of Rockwood Meteorite.

The rocky part, after being freed as well as possible from metal, was finely ground and digested with dilute hydrochloric acid, and the resulting soluble and insoluble portions investigated separately, but from the fact of there being a number of minerals mixed together no satisfactory conclusions could be drawn from the examination. The mass was therefore analyzed as a whole with the following results:

| | Per cent. | |
|---|---|---|
| $SiO_2$ | 41.92 | |
| $Al_2O_3$ | 9.27 | |
| FeO | 22.94 | |
| CaO | 9.09 | |
| MgO | 8.76 | |
| Fe | 3.75 | |
| Ni | 1.74 | |
| Cl | 0.18 | = 0.32 $FeCl_3$ |
| P | 0.65 | |
| S | 1.58 | |
| | 99.88 | |

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By the analysis of the portions soluble and insoluble in dilute acid it was found that the greater part of the lime and but a trace of the magnesia had gone into solution, proving the absence of olivine, and giving good grounds for the supposition that the rocky portion is mainly a mixture of anorthite and a silicate related to augite, but very rich in iron. It will be noticed that the ratio between the iron and nickel in the metallic portion is greater than that in the rock. This is accounted for by the fact that in the rocky part of the meteorite the iron, as metal, has been greatly oxidized, as is shown by the large amount of rust covering the specimen, caused no doubt by the chloride of iron present, and is reckoned as FeO, accounting for the large proportion of iron in the supposed augite.

Owing to the bad condition of the fragments subjected to analysis we have no grounds on which to compute the phosphorus and sulphur as schreibersite and troilite, but from the fact of these minerals being among the more common constituents of this class of meteorite, and also that in the main analysis of the rock portion phosphorus and sulphur were found, it is probable that the phosphide and sulphide of iron are two of the minerals present.

One of the polished slices contained a small nodule, which was sacrificed in order that its nature might be determined, and the following figures give the results of analysis. The mineral was finely ground, the metallic portion, if any, separated by aid of the magnet, and the residue was digested in dilute hydrochloric acid.

The insoluble portion was found to be 94 per cent., the composition of which is

| | Per cent. |
|---|---|
| $SiO_2$ | 51.85 |
| $Al_2O_3$ | 4.52 |
| FeO | 13.26 |
| CaO | 1.09 |
| MgO | 29.28 |
| | 100.00 |

This gives the ratio of R″O to $SiO_2$=.93 : .86, which corresponds well with the mineral enstatite, although in this case much of the magnesia is replaced by iron. The soluble portion consisted of iron with a slight trace of nickel, which tends to show that the nodule contained some metallic particles which it was impossible to extract with the magnet. During the digestion in acid, as no sulphuretted hydrogen could be detected, we infer the non-existence of sulphides in the nodule.

The total mineral was also analyzed with the following results:

| | Per cent. |
|---|---|
| $SiO_2$ | 49.96 |
| $Al_2O_3$ | 4.75 |
| FeO | 15.97 |
| CoO + NiO | trace. |
| CaO | 1.15 |
| MgO | 28.15 |
| | 99.98 |

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This meteorite, then, is a lithosiderite, poor in metal, the metallic portion not exceeding 16 per cent. of the mass. The stony part is probably anorthite and enstatite.

*Chattooga County Meteorite.*—This mass of meteoric iron was found by Mr. W. J. Fox, about the 27th of March, 1887, on his farm near Holland's Store, Chattooga county, Ga. In all 12.5 kilos were found, but the mass was rather roughly handled, being broken into pieces and some of them worked into horseshoes and nails by the local blacksmiths. Three of the fragments were obtained by Mr. G. F. Kunz, of New York city, and described by him in the December, 1887, number of the American Journal of Science.

The material received from Mr. Kunz for analysis gave the following results:

| | Per cent. |
|---|---|
| Fe | 94.60 |
| Ni | 4.97 |
| Co | .21 |
| P | .21 |
| Cl, Ss | traces. |
| | 99.99 |
| Specific gravity | 7.801 |

*Taney County Meteorite.*—We received from Mr. George F. Kunz, the present owner of this meteorite, the material for analysis. The description has been fully given by him in the December, 1887, number of the Am. Journal of Science.

This being one of the class termed stony meteorites, a number of analyses were made on the rocky portion, in order, if possible, to ascertain the character of the minerals present.

The analysis of the metallic part is as follows:

| | Per cent. |
|---|---|
| Fe | 89.41 |
| Ni | 10.41 |
| Co | .29 |
| P | .16 |
| | 100.27 |

Of the rock material separated from metallic grains the analysis gave

| | Per cent. |
|---|---|
| $SiO_2$ | 45.88 |
| $Al_2O_3$ | 7.89 |
| FeO | 19.73 |
| CaO | 6.02 |
| MgO | 17.96 |
| NiS | 1.67 |
| FeS | .54 |
| | 99.69 |

The fragment as received gave a specific gravity of 4.484. As far as I can judge the insoluble mineral of the rocky portion is enstatite, and the soluble part a lime-iron silicate with considerable $Al_2O_3$. Of the

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portion insoluble in dilute hydrochloric acid the following figures are the results of analysis:

| | | | |
|---|---|---|---|
| $SiO_2$ | 52.39 | =.87 | |
| $Al_2O_3$ | 7.11 | | |
| FeO | 14.68 | .20 | .81 |
| CaO | 4.49 | .08 | |
| MgO | 21.33 | .53 | |
| | 100.00 | | |

Ratio of $SiO_2 : R''O = .87 : .81$ which agrees pretty well with enstatite; but here the MgO is replaced by much FeO, and the presence of $Al_2O_3$ makes the ratio vary a little from the normal 1 : 1. Deducting all the S as NiS and the Fe to correspond to the remaining S from the soluble part, we have for the percentage of the soluble part:

| | Per cent. |
|---|---|
| $SiO_2$ | 26.95 |
| $Al_2O_3$ | 17.69 |
| FeO | 35.98 |
| CaO | 15.98 |
| MgO | 3.40 |
| | 100.00 |

The little MgO here probably comes from the slight solubility of the enstatite in the hydrochloric acid.

This meteorite is similar to the so-called Newton county, Ark., stone described by Dr. J. L. Smith,[1] and Mr. Kunz has found that the mass originally fell in Taney county, Mo., but that a fragment was broken off and taken to Newton county, Ark.

*Linnville Mountain Meteorite.*—About the year 1882 a mass of meteoric iron was found on Linnville Mountain, Burke county, N. C. Eventually it came into the hands of Mr. Kunz and was described by him in the American Journal of Science.[2]

Material for analysis was furnished by Mr. Kunz and gave the following results:

| | Per cent. |
|---|---|
| Fe | 84.56 |
| Ni | 14.95 |
| Co | .33 |
| Cu | none. |
| S | .12 |
| C | trace. |
| P | trace. |
| | 99.96 |

*The Fayette County Meteorite.*—The meteorite described below was found some ten years ago at Bluff, a settlement on the Colorado River about three miles southwest of the town of La Grange, in Fayette county, Tex. Bluff can not boast of being a village, as it is simply made up of a few farms scattered within a radius of two miles. The farmers are

[1] Am. Jour. Science, vol. 40, 1865. [2] Ibid., vol. 36, Oct., 1888.

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mostly Germans or Bohemians, and as they are generally of the superstitious class, it is not strange that the finder, a Bohemian, named Raniosek, should have been struck by the appearance of the stone, and especially by its weight. As it is probable that he never heard of such a thing as a meteorite, it is safe to say that he did not know the nature of his find; still he seems to have come to the conclusion that it was something foreign to the soil.

There is a tradition in Fayette county that Santa Aña, at the time of his flight after the battle of San Jacinto, buried his war treasures somewhere near La Grange, and the belief has so fixed itself in the minds of the inhabitants that many fruitless attempts have been made to discover them. The finder of the meteorite, with the tradition fresh in his mind, reasoned that so large and heavy a stone must mark the place where some treasure was deposited; he therefore rolled the stone a few feet aside and dug a deep hole at the exact spot where the stone had been, without finding anything to pay him for his labor.

For several years the stone lay where the Bohemian had left it; then he sold the piece of land to Mr. C. Hensel, who still owns it; but before the latter had taken possession Raniosek removed the stone to his own farm, about a mile away, where for five years more it lay neglected in his yard. His reason for removing it was that its weight led him to suspect it contained some valuable metal.

About three years ago Mr. H. Hensoldt took charge of the school at Cedar, two and one-half miles from Bluff settlement. While spending his time in hunting for fossils, minerals, etc., the attention of the farmers was drawn to him, and in January, 1888, he was informed of the str nge stone in Mr. Raniosek's yard. Immediately on seeing it he recognized it as a meteorite, and a very fine specimen of its kind.

After obtaining possession of the stone Mr. Hensoldt disposed of it to Messrs. Ward and Howell, of Rochester, N. Y., to whom we are indebted for the material for study and the privilege of description. On receiving the stone Mr. Howell published a notice in Science (February 3, 1888, p. 55) putting it on record as the "LaGrange Meteorite," but on finding that this name had already been applied to the Oldham County, Ky., Meteorite, agreed that it should be called the Fayette County Meteorite.

The stone possesses all the characteristics of a meteorite. The pittings are well marked, but the crust shows only in the deeper depressions; a freshly fractured surface shows, besides the grains of metal, a greenish-gray appearance not unlike some greenstones. A particularly interesting feature of the stone is the presence of a few dark-colored veins varying greatly in dimensions—the one in the specimen for examination being some 2mm in the greatest width and 60mm in length.

The three dimensions of the mass are 58cm × 46cm × 28cm, and the total weight about 146 kilos. A good idea of the appearance of the meteorite may be had from figure 7.

Before the specimen was pulverized for analysis the vein was care-

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fully sawed out, so as to keep all the vein material from the mass. The rock was then ground as fine as possible, and a portion (1 gram) treated with iodine in cold water, to separate the metallic particles. The residue

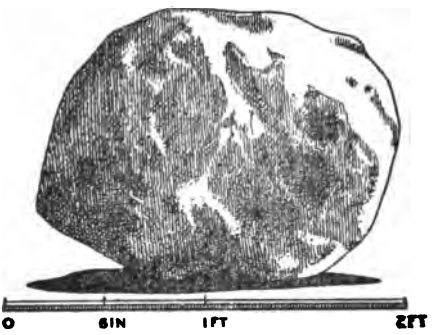


FIG. 7.—The Fayette County Meteorite.

was filtered on a Gooch soluble filter and washed free from iodine. The rocky material, after being weighed, was treated with dilute hydrochloric acid and allowed to stand for some time, then filtered, and the residue weighed; in both cases the mineral being separated from the filter by using the proper solvent for the anthracene—washed with ether and alcohol and dried at 100° C. This temperature was not sufficient to drive all the water from the mineral part, which accounts for the discrepancy of about 2 per cent.

The following figures will show the composition of the metal and the rock, soluble and insoluble, in hydrochloric acid; also the results of a complete analysis of the total mass:

| | No. 1. | No. 2. | No. 3. | No. 4. |
|---|---|---|---|---|
| | Total mass. | 5.67 per cent. of total (metal). | 33.3 per cent. of total (insoluble in HCl). | 60.62 per cent. of total (soluble in HCl). |
| $SiO_2$ | 37.70 | ..... | 49.64 | 33.59 |
| Fe | 3.47 | 82.42 | ..... | ..... |
| FeO | 23.82 | ..... | 15.56 | 31.12 |
| $Al_2O_3$ | 2.17 | ..... | 4.12 | 1.34 |
| $P_2O_5$ | .25 | ..... | ..... | .42 |
| CaO | 2.20 | ..... | 4.93 | 1.00 |
| MnO | .45 | ..... | .54 | .43 |
| MgO | 25.94 | ..... | 25.21 | 28.08 |
| NiO | 1.59 | ..... | trace. | 2.66 |
| Ni | .65 | 15.44 | trace. | ..... |
| CoO | .16 | ..... | trace. | .27 |
| Co | .09 | 2.14 | ..... | ..... |
| S | 1.30 | ..... | ..... | 2.18 |
| | 99.79 | 100.00 | 100.00 | 101.09 |
| Less O for S | .65 | ..... | ..... | 1.09 |
| | 99.14 | ..... | ..... | 100.00 |
| Specific gravity | 3.510 | ..... | ..... | ..... |

The percentages in all except the first are calculated from the weight found.

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From these figures it will be seen that the minerals which go to make up the rocky portion of the meteorite are essentially olivine and enstatite, with considerable pyrrhotite, as is also shown by the microscopical description, for which I am indebted to Mr. G. P. Merrill, of the U. S. National Museum, by whom the paper was published in the American Journal of Science.[1]

The stone belongs to the class of meteorites to which G. Rose[2] has given the name "chondrites." To the unaided eye the chronditic structure is not distinctly marked, a broken surface showing a fine-grained and evidently crystalline granular rock, very compact, of a greenish-gray color, and thickly studded with small metallic points with a brassy luster. A polished surface shows the stone to be composed of small chondri rarely over 2mm in diameter, thickly and firmly compacted in a fine granular groundmass. Throughout the entire mass are thickly distributed innumerable small irregular flecks of a steel-gray, brassy, and bronze-yellow color, presumably native iron and pyrrhotite.

The striking feature of the stone is its fine and compact texture, which exceeds that of any chondritic meteorite with which we are acquainted, but which is perhaps most closely approached by the stones of Dhurmsalà, India, and Cabarrus county, N. C.

Thin sections of the stone show, under the microscope, a confused aggregate of rounded and irregular, often fragmental, olivine and enstatite grains and chondri, embedded in a fine granular groundmass of the same mineral composition.

The chondri occur in both monosomatic and polysomatic forms composed either of olivine or enstatite alone or the two minerals associated. The peculiar grate-like or barred forms so characteristic of olivine chondri are here represented, as are the radiating fan-shaped forms of enstatite.

The large greenish microscopic chondri are, under the miscroscope, seen to be made up of innumerable enstatite granules so arranged as to form oval or fan-shaped areas of radiating columns, inclosing large, quite perfectly outlined crystals of the same mineral. These included forms are nearly colorless or merely gray through inclosures of innumerable dust-like particles, and show sharp and well-defined cleavages parallel to either prism and a parting parallel to the orthopinacoid. Both olivine and enstatite are nearly colorless or gray through inclosures of dust-like particles, and carry but few cavities.

In addition to the minerals above mentioned there were noticed occasional broad, irregular plates of a monoclinic mineral, light gray in color, but polarizing brilliantly in red and yellow colors, and which gave extinction angles varying from 25° to 31° Such are presumably augite or a closely allied pyroxene. Nothing that can be certainly identified as a feldspar was observed. Occasional small nearly colorless angular forms show faint indications of twin structure, and it is possible may

[1] Whitfield & Merrill: Am Jour. of Science, vol. 36, Aug. 1888.
[2] Abhandl. der königl. Akad. d. Wissensch. zu Berlin, 1863, p. 1861.

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be a plagioclase. In two sections were observed irregular outlined interstitial areas perfectly colorless and full of gas cavities. These in some cases remained quite dark during a complete revolution of the stage, and in others gave decided polarization in light and dark colors, and in converging light showed indistinct biaxial interference figures. The position of these areas relative to the other constituents is that of an interstitial glass or a secondary mineral like a zeolite. As they show neither cleavage nor crystallographic outlines, and moreover are to be found but rarely in the sections at hand, it is impossible to identify them satisfactorily.

The metallic iron occurs in the usual rounded and irregular masses one to two millimeters in diameter, and is apparently in about equal proportions with the pyrrhotite: the latter showing a bright brassy luster in strong contrast with the silvery white iron.

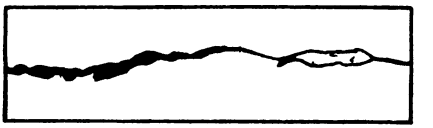

FIG. 8.—Vein in Fayette County Meteorite.—Natural size.

The black vein above noted traverses the stone in the form of an irregular fissure (often expanding and contracting abruptly, as is shown in Fig. 8), for a distance of about 60mm, and varies in width from a mere line up to 2mm. Near its lower end it bifurcates, and incloses a portion of the mass of the meteorite some 15mm long by 2mm wide.[1]

From a fragment containing a portion of the vein thin sections were prepared, and the remaining vein material, separated as clearly as possible from the inclosing rock, was subjected to chemical analysis, the process being essentially the same as in the analysis of the meteorite proper. Although the vein material is more compact and much darker in color, the analysis shows very little difference from that of the mass, the main apparent difference being the absence of the lime bearing mineral. The following are the figures obtained by analysis on material that weighed a little less than 0.4 grams:

| | Metal. | | 44 per cent. of vein. Insoluble in HCl. | 51 per cent. of vein. Soluble in HCl. |
|---|---|---|---|---|
| Fe | 2.30 | $SiO_2$ | 56.52 | 27.63 |
| NiCo | trace. | FeO | 12.35 | 34.31 |
| | | $Al_2O_3$ | 1.51 | 2.41 |
| | | CaO | trace. | trace. |
| | | MgO | 25.53 | 32.12 |
| | | (NiCo) O | 4.09 | 3.27 |
| | | S | | .52 |
| | | | 100.00 | 100.26 |
| | | Less O for S | | .26 |
| Specific gravity | 3.585 | | | 100.00 |

[1] Since the above was written Messrs. Ward and Howell have sliced the stone through the center and published in Science of June 1, 1888, a figure showing the full extent and width of the veins.

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The same difficulty, with regard to water in the mineral, exists here as in the analysis of the mass.

From the figures it appears that the portion soluble in hydrochloric acid is essentially olivine in composition, while the insoluble is evidently a mixture of the same insoluble constituents as the mass of the meteorite. The filling material of the vein is, to the unaided eye, quite black and without luster; under the microscope it is seen to penetrate very irregularly and by innumerable minute vein-like ramifications into the stony mass on either side, and to carry numerous inclosures of a colorless mineral substance and blebs of metallic iron and pyrrhotite. The exact nature of the colorless inclosures can not be ascertained. On treating an uncovered slide with hydrochloric acid a part of these were dissolved, others were unacted upon. Under the microscope they are full of irregular rifts and fracture lines, but show no true cleavages. Some of them are in the form of single individuals, others have the structure of fragments of polysomatic chondri. Nearly all contain included black amorphous material, and many show distinctly included specks, giving the silvery white and brassy yellow reflections of the metallic iron and pyrrhotite. In many cases they are not separated from the black vein material by sharp lines, but seem to pass into it by gradations. Between crossed nicols many of them act like a gum, others remain always light, recalling the well-known crypto-crystalline structure of chalcedony, and still show here and there occasional small areas giving the characteristic polarization colors of olivine and enstatite. On examining the walls of the vein areas were observed where the gray and yellowish enstatites and olivines retained their normal properties at the distance of one or two millimeters, but at contact with the black-vein matter were reduced to the colorless non-polarizing condition of the inclosures.

The black matter of the vein when viewed in strong reflected light shows a dull bronze luster, less brilliant than that of the pyrrhotite particles which it incloses. The thinnest portions of the slide when examined with a power of 175 diameters show a brownish amorphous base through which are scattered abundant irregular dust-like particles and flecks of a perfectly black opaque material, the nature of which it is impossible to ascertain by the microscope alone.

The structure of the vein is shown in figure 9, in which the finely dotted portions represent the black amorphous vein matter with bronzy luster, the entirely black areas, the blebs of metal and pyrrhotite, and the irregularly rounded clear or partly clouded areas the colorless silicates.

From the study of these veins as above described we are inclined to consider the colorless particles as olivine and enstatite residuals which have been deprived of their normal optical properties by the forces active in forming the vein. What the exact character of the black and amorphous material may be still remains a matter of conjecture. It

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is unacted upon by acids, and when tested with a needle point it breaks up readily into earthy fragments which are not attracted by the magnet.

Mr. Howell informs me that the stone in his possession shows three of these veins, the largest exposure of any one on a broken surface being about four inches. The width and general character of all, he states, appear to be uniform throughout, though this can be ascertained definitely only by breaking the stone.[1]

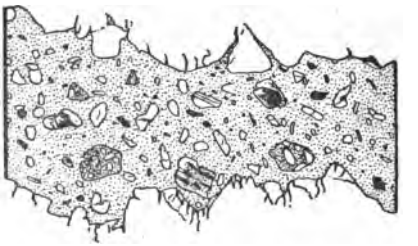

FIG. 9.—Portion of vein highly magnified.

Owing to the small amount of vein material which was available for chemical analysis and the impossibility of separating it completely from the inclosing rock, the results obtained can be regarded only as suggestive. The main points brought out can be best shown by reproducing here a comparison of the results:

| | Mass of meteorite. | Vein material. |
|---|---|---|
| $SiO_2$ | 37.70 | 38.96 |
| Fe | 4.41 | 2.30 |
| FeO | 23.82 | 22.98 |
| $Al_2O_3$ | 2.17 | 1.89 |
| CaO | 2.20 | trace. |
| MnO | .45 | ..... |
| MgO | 25.94 | 27.52 |
| Ni, Co | 1.75 | 3.26 |
| S | 1.30 | .26 |
| Specific gravity | 3.510 | 3.585 |

[1] In structure these veins seem to only remotely resemble those described by Tschermak (Sitz. der kais. Akad. der Wiss., vol. 85, Part 1, p. 204) in the Mocs meteorite, and which, it will be remembered, he argued indicated an elevation of temperature since the consolidation of the stone, such as, aided by reducing vapors and gases, fused the iron and pyrrhotite without affecting the silicates. He describes the brown and black "Fullmasse" of the vein as an admixture of the same substance as the meteorite itself, and an opaque half glassy black admixture resembling the black vein-like material of the Orvinio stone. The silicates occur in the vein in the form of small sharp splinters, the iron in granules, and the pyrrhotite in the form of little leaves and small kernels, often so arranged as to give rise to a fluidal structure. Dr. Hans Reusch has described (N. Jahrb. für Min., IV Beil.-Band, 3 Heft, 1886, pp. 491–492) veins in the Ställdalen meteorite which present features in part common to those of the Fayette stone. To the unaided eye the filling material is black and opaque and carries metallic particles. Under the microscope it shows a brownish gray, isotropic and sometimes glassy substance densely crowded with rounded transparent fragments. The upper figure in his Plate XIV closely resembles in structure the vein matter of the Fayette stone, but as far as can be judged from his description the included particles seem to have retained their normal optical properties. Reusch regards this black vein material as the result of a partial refusion of the chrondite substance.



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These differences are too slight to be considered of great value unless found to be constant by further investigation.

*San Bernardino County Meteorite.*—A prospector working in the San Emigdio Mountains, California, found this meteorite, and thinking it to be a lump of some valuable ore sent it to Mr. Thomas Price, of San Francisco, for assay. Unfortunately before the nature of the sample was discovered it was put through a crusher and hence only small pieces could be obtained. On finding that it was a meteorite, Mr. Price sent a few fragments to Mr. G. P. Merrill, of the U. S. National Museum, for investigation. Mr. Merrill has published a note on the subject in the June, 1888, number of the American Journal of Science, and later a full description in Vol. 11 of the Proceedings of the National Museum.

From Mr. Merrill we received material for analysis, but the bad condition of the fragments made a complete analysis almost impossible.

The mass consists of

| | Per cent. |
|---|---|
| Metallic portion | 6.21 |
| Soluble in HCl | 51.26 |
| Insoluble in HCl | 42.23 |

Of this the metallic portion gave as its composition—

| | Per cent. |
|---|---|
| Fe | 88.25 |
| Ni | 11.27 |
| Co | .48 |

The soluble portion is presumably all olivine and pyrrhotite, with some secondary iron oxide. The analysis of this portion by separation with dilute hydrochloric acid was a failure. The insoluble part was separated by long digestion in dilute acid followed by boiling in sodium carbonate. The remaining powder showed, with the aid of the microscope, the presence of very pure enstatite and very little else, and the chemical composition upholds this view.

| | Per cent. |
|---|---|
| $SiO_2$ | 54.42 |
| FeO | 14.03 |
| CaO | 2.46 |
| MgO | 29.11 |
| | 100.02 |

From these figures it will be seen that the mineral is a highly ferriferous enstatite (bronzite) with a small amount of a lime-bearing pyroxene mineral. The relative proportions of the various constituents as they exist in the first rock can not be estimated with any degree of certainty for the reasons already stated.

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## TWO SULPHANTIMONITES FROM COLORADO.

By L. G. EAKINS.

The mineral first to be described was sent to the Denver laboratory of the U. S. Geological Survey in the latter part of 1885 by Mr. E. R. Warren, of Crested Butte, Colo.

At that time a hasty qualitative examination was made, establishing the fact that it was a sulphantimonite of lead, and since then nothing more has been done with it until the present analysis was made.

This mineral comes from the "Domingo" mine, on the ridge between Dark Cañon and Baxter Basin, Gunnison county, Colo., in which locality it is known as "mineral wool." It consists of aggregates of small acicular crystals, forming matted, wool-like masses in the cavities of a highly decomposed gangue rock of siliceous material mixed with some calcite. It is dull grayish-black in color, with occasional spots of iridescence, due undoubtedly to a slight superficial oxidation.

In procuring material for analysis a lot of loose material sent by Mr. Warren was slightly crushed and rubbed with water in a mortar and poured off, the fine needle-like crystals floating off readily; this was afterward purified by a retreatment in the same manner, and then subjected for a short time to the action of dilute hydrochloric acid to remove the slight amount of attached calcite. The material obtained in this manner appeared under the microscope to be perfectly pure and homogeneous, with the exception of a slight amount of gangue still remaining.

No crystalline form could be made out, and on account of its peculiar nature no attempt has been made to determine either specific gravity or hardness. Heated before the blow-pipe it fuses readily without decrepitation; in the closed tube it gives a slight sublimate of sulphur only; in the open tube it gives off sulphurous acid and dense white fumes of oxide of antimony; heated strongly the antimony all volatilizes, leaving a fused residue of sulphate of lead, slightly colored by the iron present; on charcoal it gives the lead and antimony coatings, and in the reducing flame with soda a lead button. It is soluble in hot strong hydrochloric acid with evolution of hydrogen sulphide.



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The analysis is as follows:

| | | Atomic ratios. | |
|---|---|---|---|
| Ag | trace. | | |
| Cu | trace. | | |
| Pb | 39.33 | ÷207 = .190 | .222 |
| Fe | 1.77 | ÷ 56 = .032 | |
| Mn | trace. | | |
| Sb | 36.34 | ÷120 = | .303 |
| S | 21.19 | ÷ 32 = | .662 |
| Insoluble gangue | .52 | | |
| | 99.15 | | |

Dividing these atomic ratios by .222, we get:

| | | |
|---|---|---|
| Pb, Fe | 1.00 | = 3.00 |
| Sb | 1.36 | 4.08 |
| S | 2.98 | 8.94 |

Giving the formula: $(Pb, Fe)_3Sb_4S_9$, or $3(Pb, Fe)\,S, 2Sb_2S_3$.

This mineral, it is seen, fills a place in the group, $3RS, 2(As, Bi, Sb)_2S_3$, of which there are but few good examples, and which until now has not had an antimony representative.

The somewhat low summation of the analysis is probably due to two causes: First, a small amount of soluble gangue which was present and undetermined; second, the sulphur is about four-tenths of one per cent. less than required, due to the slight natural oxidation of the mineral together with an additional amount induced by treatment with dilute hydrochloric acid for the removal of calcite. In addition to the complete analysis given, there were additional determinations made of lead, antimony, and sulphur, the results obtained being in strict agreement with those given above.

The second of these sulphantimonites was collected in the summer of 1887, by Mr. Whitman Cross. It comes from a mine on Augusta Mountain, Gunnison county, Colo., this locality being about one mile east of the "Domingo" mine. Locally this mineral is also known as "mineral wool," and although differing considerably in appearance from the one just described, they were, on account of the similarity of occurrence, considered as probably identical.

It occurs in a siliceous gangue together with pyrite and sphalerite, and forms groups of acicular crystals, which are elongated prisms deeply striated, but whose form could not be determined.

The individual crystals of this mineral are considerably larger than those of the one previously described, and in consequence they do not tend so much to form matted aggregates. Its color is a bright, steely, grayish-black, with no tendency toward tarnish or iridescence. The separation of this mineral from the accompanying ones and the gangue was a matter of considerable difficulty. On account of their size the crystals could not be successfully washed out from the other material, but by the use of a rapid current of water and the Thoulet method a small quantity was finally procured perfectly free from everything except

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some pyrite, and that had no effect upon the analysis, as the mineral was dissolved in a mixture of hydrochloric and tartaric acids, leaving the pyrite unattacked. It was then filtered through a Gooch crucible, and the amount of pyrite determined and deducted from the material taken. The fact that but a trace of iron was found in the analysis is conclusive proof that the pyrite was practically unattacked.

Blow-pipe characteristics are the same as in the one before described. The analysis is as follows:

| | | Atomic ratios. |
|---|---|---|
| Ag | trace. | |
| Pb | 55.52 | $\div 207 = .268$ |
| Fe | trace. | |
| Sb | 25.99 | $\div 120 = .217$ |
| S, (calculated) | 18.98 | $\div 32 = .593$ |
| | 100.49 | |

Dividing these atomic ratios by .217 we get:

| | | |
|---|---|---|
| Pb | 1.24 | $= 4.96$ |
| Sb | 1.00 | 4.00 |
| S | 2.74 | 10.96 |

Giving the formula:—$Pb_5Sb_4S_{11}$ or $5PbS, 2Sb_2S_3$.

We have here, in formula, a freieslebenite in which instead of lead and silver the silver has been completely replaced by lead, and although the crystallographic agreement of this mineral with freieslebenite has not been established, there seems to be no good reason for not referring it to that species. The first described of the above minerals, 3 (Pb, Fe) S, 2 $Sb_2S_3$, has been given the name "Warrenite," after the gentleman who brought it to our notice. The same mineral has been designated "domingite" by Groth.

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# COEFFICIENTS OF VOLATILITY FOR AQUEOUS CHLORHYDRIC ACID.

By ROBERT B. WARDER.

The various questions of physical chemistry are claiming more and more attention, and problems relating to states of aggregation seem to have a special interest. The art of fractional distillation on a manufacturing scale has developed a great variety of appliances, but much remains to place the theory on a satisfactory mathematical basis, especially in the case of bodies which exert a mutual affinity.

The term "coefficient of volatility" was introduced by Wanklyn[1] to indicate the relative readiness of different constituents to volatilize. Thus he found that when a very dilute solution of ammonia was distilled until $\frac{1}{10}$ of the water passed over, nearly $\frac{1}{2}$ of the ammonia had distilled with it. He estimated that a given quantity of water in any small fraction of the distillate was accompanied by 13 to 14 times as much ammonia as the same quantity of water in the boiling liquid. Expressed more formally, if a boiling liquid has the composition $H_2O+n NH_3$, and yields a mixed vapor represented by $H_2O+vn NH_3$, the factor $v$ is the coefficicient of volatility, and in the case cited $v$ equals about 13 or 14. Since this gas may be absorbed in indefinite proportions, of course the coefficients $n$ and $vn$ may be fractional, indicating the number of molecules of $NH_3$ divided by the number of molecules of $H_2O$.

In the case of chlorhydric acid, as is well known, when the liquid boils under the ordinary atmospheric pressure, it tends to acquire the constant composition $HCl+8H_2O$, or $H_2O+\frac{1}{8} HCl$. After a stronger or weaker acid has reached this composition, on further boiling $n=vn$ and the factor $v$=unity.

The well known researches of Roscoe and Dittmar[2] showed that an acid of higher composition will boil unchanged under diminished pressure; a similar result was observed upon evaporation in a current of air of given temperature to supplement the partial pressure exerted by acid and aqueous vapor. Hence it is clear that $v$ depends not only upon the composition of the mixture, but also upon the pressure (or temperature) at which the distillation is conducted. The published

[1] Philos. Magazine, [4] 45, 129 (1873). Pharm. J. Trans., [3] 3, 543 (1873).
[2] Jour. Chem. Soc., 12, 128.



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data relate to the conditions under which $v=1$, but no attempt has yet been made to show the relation between $v$ and $n$.

The more recent researches of Roozeboom show certain conditions of equilibrium among solid, liquid, and gaseous phases of aqueous chlorhydric acid[1] and other compounds which are illustrated by thermodynamical theory;[2] but the papers do not discuss the ordinary conditions of distillation.

Many operations of manufacturing, geological, and analytical chemistry depend upon the partial or complete separation of volatile constituents. Chlorhydric acid is typical of a large number of substances which have strong attraction for the solvent; and a more exact knowledge of its *volatility* as a function of the *composition* is the object of this research.

## EXPERIMENTAL METHOD.

One hundred cubic centimeters of chlorhydric acid of known strength was subjected to fractional distillation in a boiling flask of 250cm³ capacity. Successive portions of the distillate were conducted through a Liebig condenser and discharged near the bottom of receivers; a loosely fitting cork was used to hinder evaporation. The several fractions, after weighing in well stoppered vessels, were titrated with sodium hydrate, containing a little barium hydrate and carefully protected from the air by soda lime. Phenol phthalein was used as indicator. In some cases very weak distillates were evaporated with excess of ammonia, and titrated with centinormal silver solution and potassium chromate. The water was determined by deducting the acid from the total weight of the fraction. As a rule no reliance was placed upon specific gravity, the ordinary summer temperature of the room being far above that recognized in the tables; hence the acid used for each distillation was weighed. The residues in the boiling flask were also weighed and titrated for control.

When fractional distillation is conducted for the purpose of separating the constituents, this is promoted by some kind of dephlegmation; this may be accomplished by exceedingly simple means, as the walls of an ordinary boiling flask, by the complicated appliances of the manufacturers, or by the many devices for laboratory use. The object of the present work required the exclusion of dephlegmation, since this would introduce an element of great uncertainty. The flask was placed in a cylindrical air bath and covered with a conical hood of sheet copper. By means of a ring burner (as devised by Gibbs), with very gentle air blast, a circle of gas jets was thrown upon the copper cone, so as to keep the upper part of the flask heated far above the boiling point

[1] Rec. Trav. Chim. Pays-Bas, 3, 84 (1884). Abstract in Zeitsch. physik. Chem., 1, 365 (1887) and 2, 459, (1888).

[2] Rec. Trav. Chim. Pays-Bas, 5, 335 (1886). Abstract in Zeitsch. physik. Chem., 2, 462 (1888).

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of the fluid, while distillation was effected by a large Bunsen burner under the air bath. A thermometer in the vapor was usually kept at a temperature of 145° to 153°. The boiling point of the liquid was from 100° to 109 C. (varying with the concentration); and from the rate of distillation and the space above the liquid, it was estimated that the vapor would pass from the surface to the condenser in about six seconds; hence it is not to be supposed that the thermometer indicated the actual temperature of the vapor, but something between this and the temperature of the radiating surface of glass or copper. By this means the condensation of moisture upon the sides of the flask was prevented. In a preliminary experiment with $H_2O+.037HCl$, the first fifty per cent. distilled without the hood and ring burner contained no more acid than the 10 per cent. distilled with the precaution described; and this was only one-twentieth as much acid as distilled in the first 50 per cent. under the heated cover.

As the distillation proceeded, and the volume of vapor increased, the temperature had to be moderated by turning down the flame.

In the distillation of strong acid each receiver was weighed with $10cm^3$ water, to absorb the acid fumes.

## CALCULATION OF RESULTS.

The weight of HCl found in each fraction of the distillate subtracted from the total weight, leaves the weight of water; and the weights of water and acid thus found in each fraction were subtracted successively from the water and acid taken to find the composition after the removal of this fraction. The mean composition of the boiling liquid during the removal of each fraction was expressed in the form $H_2O+nHCl$, the composition of the distillate being $H_2O+n'HCl$ or $H_2O+vnHCl$. The coefficient $v$ was then found by dividing $n'$ by $n$. Four distillations gave 25 pairs of values as follows:

| I. | | II. | | III. | | IV. | |
|---|---|---|---|---|---|---|---|
| $n$ | $v$ | $n$ | $v$ | $n$ | $v$ | $n$ | $v$ |
| .0952 | .284 | .0681 | .140 | .0666 | .084 | .1939 | 5.44 |
| .1031 | .423 | .0759 | .194 | .0693 | .111 | .1853 | 3.71 |
| .1107 | .537 | .0862 | .282 | .0730 | .158 | .1713 | 2.40 |
| .1186 | .645 | .0984 | .429 | .0769 | .172 | .1567 | 1.66 |
| .1231 | .868 | .1107 | .597 | .0806 | .198 | .1474 | 1.31 |
| | | | | .0844 | .243 | | |
| | | | | .0879 | .247 | | |
| | | | | 0911 | .253 | | |
| | | | | .0944 | .300 | | |
| | | | | .0970 | .311 | | |

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## DISCUSSION OF RESULTS.

Two points remain to be considered:

First. What formula will best express the values found for $v$ as function of $n$?

Second. Do the relations here determined point to actual equilibrium between liquid and vapor?

No one equation was found to express all the values given above. When dilute acid ($n$=.07 to .11) was boiled rapidly (about one gram per minute) the results agreed with the equation

$$v=445n^3,$$

as in series II. When strong acid ($n$=.15 to .20) was boiled rapidly, the values of $v$ were somewhat greater than would be indicated by the equation above; approximately,

$$v=3063n^4,$$

as in series IV. These two empirical curves, which occupy different parts of the field, are entirely consistent with each other, but must be regarded as a *first approximation only* to the function sought. When the dilute acid of Series I and III was boiled from 20 to 60 per cent. more slowly than that of Series II, the values of $v$ were about 10 to 30 per cent. less than those indicated by the equation. There can be little doubt that $v$ is a function of the rate of boiling as well as of the composition of the liquid. The problem appears to be dynamical, not a question of equilibrium merely, and I hope to investigate this point further.

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# ANALYSES OF JADE.

By F. W. CLARKE.

In the ethnological collections of the U. S. National Museum there are many objects of jadeite, nephrite, and various jade-like stones. They represent a wide range of localities, especially as regards the North American specimens, and in their external characteristics they exhibit great variety of color, texture, and quality. Some came from regions which have already been well studied, but others, as in the series of articles from Alaska and Costa Rica, seemed to merit further investigation. At the earnest desire of the late Professor Baird, their mineralogical description was undertaken by Mr. G. P. Merrill and myself, and our joint paper, giving my analyses and his microscopic examinations, has already been published by the National Museum.[1] The present communication contains merely my own portion of the work, as part of the year's record of the chemical laboratory.

In Alaskan specimens of jade the museum is particularly rich. Since the acquisition of that territory by the United States it has been visited by many official expeditions, and their assembled collections represent the entire coast-line from Point Barrow to the southernmost extremity. If we except the remarkable hammers of jade-like pectolite described by me some years ago,[2] all of the Alaskan jades are true nephrites, undistinguishable in most particulars from the nephrites of Siberia, New Zealand, or the Swiss Lake Dwellings. In general this nephrite is coarse in quality; but occasionally objects are seen having high finish, some translucency, and great beauty. The following worked specimens were examined, the material for analysis being in each case carefully sawed off to avoid unnecessary damage to the object.

A. Part of a small adze, Cape Prince of Wales. Yellowish-green, mottled. Specific gravity 2.989.

B. Material for a drill, St. Michael's. Siskin green, translucent, uniform in texture. Specific gravity 3.006.

C. Small knife, Diomede Island. Blackish-green, mottled and laminated. Specific gravity 3.010.

D. Adze, Point Barrow. Nearly black superficially, opaque. Specific gravity 2.922.

[1] Proc. U. S. N[illegible]m, 1888. [2] Bull. U. S. Geological Survey, No. 9, p. 9.



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The specific gravity determinations were made by Dr. William Hallock. The analyses, by myself, were as follows:

| | A. | B. | C. | D. |
|---|---|---|---|---|
| Ignition | 1.91 | 1.42 | 2.03 | 2.06 |
| $SiO_2$ | 56.01 | 56.12 | 56.08 | 57.11 |
| $Al_2O_3$ | 1.98 | .63 | 1.01 | 2.57 |
| FeO | 6.34 | 7.45 | 7.67 | 5.15 |
| MnO | trace. | trace. | trace. | trace. |
| CaO | 12.54 | 12.72 | 13.35 | 11.54 |
| MgO | 21.57 | 20.92 | 19.96 | 21.38 |
| | 100.35 | 99.26 | 100.10 | 99.81 |

In each case the ferrous oxide represents the *total* iron. Ferric oxide was not discriminated, nor were alkalies looked for. So far the analyses are incomplete.

In addition to the above-named implements, another object of supposed jade was examined. It was a flaker from Point Barrow, of a dull bluish-green color, conchoidal fracture, considerable translucency, and specific gravity 2.654. These data, together with a partial analysis, identify the object as quartz. It contained 97.79 per cent. of silica.

Concerning the origin of the Alaskan jades there has been much discussion. Some early writers ascribed it to Siberian sources, but of late years evidence has been gathered pointing to a home locality. Native reports indicated a source known as the "Jade Mountain," which lies north of the Kowak River about 150 miles above its mouth, and after several efforts the spot has been actually visited by Lieut. G. M. Stoney. He collected specimens of jade *in situ*, and a number of specimens were submitted to me for analysis. They may be described as follows:

A. Greenish-gray, splintery-lamellar in structure.
B. Like A, but more granular.
C. Paler, nearly white, closer grained.
D. Brownish, highly foliated.

All four were analyzed with the subjoined results:

| | A. | B. | C. | D. |
|---|---|---|---|---|
| Ignition | 1.78 | 1.38 | 1.76 | 1.73 |
| $SiO_2$ | 58.11 | 55.87 | 56.85 | 57.38 |
| $Al_2O_3$ | .24 | 2.07 | .88 | .19 |
| $Fe_2O_3$ | 5.44 | 5.79 | 4.33 | 4.43 |
| FeO | .38 | .38 | 1.45 | 1.25 |
| MnO | trace. | trace. | trace. | trace. |
| CaO | 12.01 | 12.43 | 13.09 | 12.14 |
| MgO | 21.97 | 21.62 | 21.56 | 22.71 |
| | 99.93 | 99.54 | 99.92 | 99.83 |

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If we connect this evidence with the microscopic evidence obtained by Mr. Merrill, it becomes clear that all the Alaskan jades are essentially identical, varying among themselves no more than specimens commonly vary from a single locality. This disposes of the theory that their presence in Alaska is to be accounted for upon the basis of trade with Siberia; which theory is also negatived by the discovery announced by Mr. G. M. Dawson ("Science," April 20, 1888, p. 186) of small nephrite bowlders on the upper part of the Lewes River, in British Columbia, not far from the eastern boundary of Alaska. But these nephrites are also strikingly like those from many other localities, and two of the latter have been included in my comparison. First, a dark green water worn bowlder from New Zealand, sent to the Museum by Sir Julius Haast; and, second, a small implement from Robenhausen, Lake Pfäffikon, Switzerland, out of the collection of Mr. Thomas Wilson. The latter specimen, also green, had a specific gravity of 3.015, as determined by Dr. Hallock. The analyses are as follows:

| | New Zealand. | Switzerland. |
|---|---|---|
| Ignition | .83 | .63 |
| $SiO_2$ | 56.73 | 56.87 |
| $Al_2O_3$ | 3.22 | 1.50 |
| FeO | 5.96 | 6.33 |
| CaO | 13.24 | 13.45 |
| MgO | 19.42 | 21.06 |
| | 99.40 | 99.84 |

All the iron is here represented as ferrous. Traces of manganese were present, but alkalies were not sought for.

Of jade objects from Mexico the Museum has a large and fine series; but nearly all of the specimens are from the one State of Oaxaca. The greater number of them are true jadeite; but as jadeite from the same region has been described by Damour,[1] a very exhaustive review of the material did not seem to be necessary. No nephrite was found in the Mexican series. Two specimens were analyzed, which may be described as follows. The specific gravity determinations are by Dr. Hallock.

A. Light-colored bead, mottled with emerald green. Specific gravity, 3.007.

B. Carved head, light green, from Zaachita. Specific gravity, 3.190.

[1] Bulletin de la Société Mineralogique, vol. 4, p. 157.

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| | A. | B. |
|---|---|---|
| Ignition | 1.81 | .53 |
| $SiO_2$ | 58.88 | 58.18 |
| $Al_2O_3$ | 25.93 | 23.53 |
| $Cr_2O_3$ | .12 | ..... |
| FeO | .24 | 1.67 |
| CaO | .40 | 2.35 |
| MgO | .36 | 1.72 |
| $Na_2O$ | 11.64 | 11.81 |
| $K_2O$ | .63 | .77 |
| | 100.01 | 100.56 |

If the water (ignition) in A. be regarded as replacing alkalies, the mineral approximates closely to normal jadeite, $AlNaSi_2O_6$. Both analyses fit in well with Damour's work.

With Central American jade objects the Museum is well supplied. A few only are from Nicaragua and Guatemala. The finest are all Costa Rican. Here too jadeite is the dominant mineral species, although with the true jades are many articles of softer green stones, and occasionally an object of quartz or chalcedony. For analysis, four specimens were chosen, viz: two jadeites, one quartz-like mineral, and one of the softer minerals, as follows:

A. Polished fragment, green. Rio de Buena Vista, Costa Rica. Specific gravity, 2.71, Clarke.

B. Jadeite fragment. Sardinal, Costa Rica. Pale green, translucent. Specific gravity, 3.32, Clarke.

C. Jadeite fragment. Culebra, Costa Rica. Light green, very granular, opaque. Specific gravity, 3.27, Clarke.

D. Small ornament. Las Huacas, Costa Rica. Dark green, very soft. Specific gravity, 2.282, Hallock.

| | A. | B. | C. | D. |
|---|---|---|---|---|
| Ignition | ..... | .90 | .93 | 10.39 |
| $SiO_2$ | 97.10 | 59.18 | 58.33 | 70.49 |
| $Al_2O_3$ | 1.85 | 22.96 | 21.63 | 11.39 |
| $Fe_2O_3$ | | | 1.71 | |
| FeO | ..... | 1.87 | .73 | 2.39 |
| MnO | ..... | ..... | ..... | trace. |
| CaO | none. | 1.52 | 4.92 | 3.83 |
| MgO | none. | .67 | 3.09 | .57 |
| $Na_2O$ | ..... | 12.71 | 8.13 | undet. |
| $K_2O$ | ..... | trace. | .22 | undet. |
| | 98.95 | 99.81 | 99.69 | 99.06 |

Of these analyses, A speaks for itself. In B and C we observe a difference in composition, which is in the line indicated by the appearance of the specimens; that from Sardinal being translucent and nearly

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homogeneous; that from Culebra being coarser, distinctly mottled, and evidently impure. Specimen C is plainly not jade in any sense. It was examined microscopically by Mr. Merrill, who pronounced it to be a highly altered volcanic tuff, containing a considerable amount of bright green chlorite.

Through the kindness of Mr. Thomas Wilson, whose collection furnished the Robenhausen nephrite already described, I have been enabled to examine several other worked specimens of minerals which are sometimes classed, though loosely, with jade. A massive "saussurite" from the Saas Valley in Switzerland, out of the Museum collection, may be conveniently included in this series.

A. Fibrolite implement from Brittany. Specific gravity, 3.147.

B. Black stone implement from Estavayer, Lake Neuchatel. Specific gravity, 3.132.

C. Dark green "saussurite" implement from Robenhausen. Specific gravity, 3.403.

D. Massive "saussurite," Saas Valley.

The specific gravity determinations are due to Dr. Hallock.

| | A. | B. | C. | D. |
|---|---|---|---|---|
| Ignition | 1.31 | .65 | .30 | .54 |
| $SiO_2$ | 34.66 | 45.13 | 46.90 | 48.29 |
| $Al_2O_3$ | 63.24 | 16.55 | 29.76 | 27.65 |
| $Fe_2O_3$ | trace. | 13.59 | 2.52 | 1.45 |
| FeO | ..... | 4.20 | | |
| MnO | ..... | trace. | ..... | ..... |
| CaO | none. | 11.02 | 11.77 | 12.95 |
| MgO | .37 | 5.48 | 5.80 | 5.36 |
| $Na_2O$ | ..... | 3.89 | 3.21 | 3.57 |
| $K_2O$ | ..... | trace. | trace. | trace. |
| | 99.58 | 100.51 | 100.26 | 99.81 |

Microscopically studied the second of the specimens was found by Mr. Merrill to be a mixture of various minerals. It is evidently a highly altered "basic rock," possibly a diorite. The saussurites need no special discussion.

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## MINERALOGICAL NOTES.

### 1. Petalite from Peru, Maine. By F. W. Clarke.

In the well-known spodumene locality at Peru, Maine, petalite has been found in abundance. The discoverer, Mr. N. H. Perry, of South Paris, Maine, kindly furnished me with a fine suite of specimens, upon which the following examination was made. The petalite is intimately and irregularly intergrown with the spodumene, and occurs in white, pearly, cleavable masses much resembling some varieties of albite. To some extent it is stained by dendritic manganese; but in general the mineral is exceedingly pure. An analysis gave the following results, the lithia being determined by Gooch's process:

| | |
|---|---|
| Ignition | 1.03 |
| $SiO_2$ | 77.29 |
| $Al_2O_3$ | 16.95 |
| $Fe_2O_3$ | trace. |
| MnO | trace. |
| $Li_2O$ | 2.62 |
| $Na_2O$ | 2.39 |
| $K_2O$ | trace. |
| | 100.28 |

### 2. Spessartite from Amelia County, Va. By F. W. Clarke.

This garnet, which is remarkable for its very high percentage of manganese, was analyzed at the request of Mr. G. F. Kunz. It occurs in the mica mines of Amelia county, in brilliant, brownish-red masses of considerable size. The specimen analyzed was very light in color, although some of the material was quite dark. The analysis was as follows:

| | |
|---|---|
| Ignition | .27 |
| $SiO_2$ | 35.35 |
| $Al_2O_3$ | 20.41 |
| $Fe_2O_3$ | 2.75 |
| FeO | 1.75 |
| MnO | 38.70 |
| MgO | none. |
| CaO | .94 |
| | 100.17 |

### 3. Oligoclase from Bakersville, N. C. By F. W. Clarke.

This mineral, which was also received from Mr. Kunz, has been described by him[1] and also by Penfield and Sperry.[2] It occurs in color-

[1] Amer. Journ. Sci. (3), vol. 36, p. 222.

[2] Amer. Journ. Sci. (3), vol. 36, p. 324.



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less or nearly colorless fragments of extraordinary transparency. Indeed, it resembles glass so nearly that at first sight one can hardly realize that it is a feldspar. The composition of the sample analyzed was as follows:

| | |
|---|---|
| Ignition | .25 |
| $SiO_2$ | 62.92 |
| $Al_2O_3$ | 25.32 |
| $Fe_2O_3$ | trace. |
| MnO | trace. |
| CaO | 4.03 |
| $K_2O$ | .96 |
| $Na_2O$ | 6.18 |
| | 99.66 |

4. WILLEMITE FROM THE TROTTER MINE, FRANKLIN, N. J. BY F. W. CLARKE.

Collected by Mr. W. S. Yeates, and at first thought to be a new mineral. The specimens obtained were nearly pure white, granular, and quite unlike ordinary willemite in appearance. The following partial analysis, however, served to determine the species:

| | |
|---|---|
| Ignition | .25 |
| $SiO_2$ | 27.41 |
| ZnO | 68.86 |
| | 96.52 |

A little manganese and iron are present, but were not determined.

5. DESCLOIZITE (?) FROM BEAVERHEAD COUNTY, MONT. W. F. HILLEBRAND.

Through Messrs. W. H. Beck and George E. Lemon, of Washington, D. C., was received for examination a large lump of friable, uncrystallized material, having a dull yellow to pale orange color, and made up mainly of a vanadate, but carrying a large percentage of gangue. Two samples as pure as could be selected from different parts of the lump were analyzed with the following results:

| | I. | II. | Mean. |
|---|---|---|---|
| PbO | 56.02 | 55.84 | 55.93 |
| CuO | 1.16 | 1.13 | 1.15 |
| FeO | 0.70 | 0.70 | 0.70 |
| ZnO | 15.96 | 15.91 | 15.94 |
| $V_2O_5$ | ..... | 20.80 | 20.80 |
| $As_2O_5$ | 0.32 | ..... | 0.32 |
| $P_2O_5$ | 0.27 | ..... | 0.27 |
| $H_2O$ | 4.37 | 4.36 | 4.37 |
| $SiO_2$ | 0.20 | 0.16 | 0.18 |
| CaO | 0.10 | ..... | 0.10 |
| MgO | 0.06 | ..... | 0.06 |
| | ..... | ..... | 99.82 |

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From I 27.62 per cent. of gangue insoluble in cold dilute nitric has been deducted, and from II 22.20 per cent. Manganese was present in the gangue in small quantity, apparently as pyrolusite, but it was not dissolved by the acid. The insoluble portion was found also to retain very small quantities of lead and zinc, which were estimated and included in the analysis as probably belonging to the vanadate. The water had to be estimated indirectly by deducting from the total amount of water afforded by the dried mixture of vanadate and gangue that belonging to the latter alone, which was found as follows: The mixture dried at 100° C., was dissolved in cold dilute nitric acid, and the insoluble matter, collected in a Gooch crucible, was dried at the same temperature, and then ignited. The loss on ignition gave the water in the gangue, there being no ferrous iron in the latter to influence the result.

Neglecting the traces of $SiO_2$, CaO, and MgO, as probably derived from the gangue, the following molecular ratio is obtained:

| | | |
|---|---|---|
| PbO | .2508 | |
| CuO | .0145 | .4718 or 4.02 |
| FeO | .0097 | |
| ZnO | .1968 | |
| $V_2O_5$ | .1140 | |
| $As_2O_5$ | .0014 | .1173 or 1.00 |
| $P_2O_5$ | .0019 | |
| $H_2O$ | .2428 | or 2.07 |

The water it will be noticed is double that required by descloizite, $R^4(OH)^2(VO^4)^2$, but in view of the liability to error inherent in the method of water estimation employed, this is not deemed sufficient cause to separate the mineral from descloizite, although the close agreement of the two water determinations, made as they were on samples containing different proportions of gangue, would indicate the correctness of the formula $R^4(OH^2)(VO^4)^2+H^2O$, which is that of descloizite with a molecule of water of crystallization added.

This, so far as known, is the first observed occurrence of a lead vanadate in Montana. The precise locality of the mineral is the Mayflower Mine, in the Bald Mountain mining district.

## 6. Preliminary Remarks on North American Uraninites

By W. F. Hillebrand.

A large crystal nearly an inch in diameter from Andrews's formerly Hales's quarry, in South Glastonbury, a few miles northeast of Middletown, Conn., showing octahedral, cubical, and dedecahedral faces, having been identified as uraninite with about 10 per cent. of thoria, the question arose: Was this thoria an essential constituent of the mineral or was its presence due to admixture of some thorium mineral, as thorite or orangite? With a view to settling this point a careful analysis was made accompanied by a microscopical examination of a thin section of the crystal. The results were not conclusive, therefore

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other material from the same locality was sought for and obtained from Prof. W. N. Rice and Mr. E. F. Sheldon of Middletown, Conn. Analysis showed its chemical identity with the first specimen, and established beyond question that the thoria could not be derived from any thorium silicate. The observation was made that unless certain precautions were taken the estimation of $UO_2$ in the mineral was very unsatisfactory, and might be many per cent. too low. If a rather concentrated sulphuric acid is used for decomposing the mineral in sealed tubes, an insoluble uranous sulphate is formed which often crystalizes out in beautiful green crystals of considerable size, which dissolve very slowly when the contents of the tubes are emptied into cold water preliminary to titration with potassium permanganate. This defect was remedied by using a very dilute acid—1 vol. $H_2SO_4$ to 6 vols. $H_2O$—and the final reaction was then as sharp as could be desired. A more important precaution to be observed is the manner of filling the tubes with carbonic acid gas. This must invariably be done by introducing the gas from a generator and sealing during its introduction, and never by using sodium carbonate in the tubes themselves. In the latter case, before the seal can be made, outside air in greater or less amount is certain to enter and its oxygen is sufficient to lower the percentage of $UO_2$ found by several per cent., as repeatedly ascertained by actual experience.

The results thus obtained after employing every possible precaution to guard against oxidation of $UO_2$ or reduction of $UO_3$ during the process of decomposing the mineral and subsequent titration were perplexing to the last degree in view of the results arrived at by Comstock[1] and Blomstrand[2] independently of each other, which appeared to prove definitely that all varieties of uraninite could be considered as orthouranates of uranium and lead, in which thorium and other metals of the earths might replace basic uranium. The Glastonbury uraninite could by no possibility be referred to an orthouranate, but was a decidedly basic salt.

In extension of the investigation uraninite from Black Hawk, Colo., from North Carolina and from Branchville, Conn., was analyzed. The North Carolina material was so evidently in process of alteration, being seamed in every direction by very minute cracks filled with yellow decomposition products, that its analysis could give no clue to the relative proportions of the two oxides of uranium in the original fresh substance, but the presence of nearly 4 per cent. of rare earths—mainly thoria—was ascertained. The Branchville material was kindly given by Professors Brush and Dana, of New Haven, being the remainder of the stock from which the material for Comstock's analysis was taken. Its re-examination was undertaken with the view of ascertaining whether thoria had not been overlooked, as would almost certainly be the case had ammonium oxalate instead of oxalic acid been employed as a test

[1] Am. Journ. Sci. (3), vol. 19, 1880, p. 220.

[2] Geol. För. Förh., VII, 59, 1884, and Journ. prak. Chem., XXIX, 191, 1884.

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for the rare earths. This proved to be the fact, there being nearly 7 per cent. of thoria present in the mineral, which had undoubtedly been included in the $UO_3$ of Comstock's analysis. This alone would utterly invalidate the formula assigned by him, but in addition the $UO_2$ was found uniformly higher by many per cent. than his analysis showed. In different samples selected from the material at my disposal, however, the percentage was not the same, but differed by several units, and the density rose always with the percentage of $UO_2$. The Colorado mineral, which unlike that from Connecticut and North Carolina does not occur crystallized, is likewise not referable to an orthouranate, being as basic as that from Glastonbury, Conn. It is remarkable for the low percentage of lead—less than 1 per cent. of oxide—and for the absence of any other qualitatively similar element, as well as for the presence of about 7 per cent. of zirconia; thoria being entirely wanting.

The question of the composition of this interesting mineral, which seemed so satisfactorily settled by the researches of Comstock and Blomstrand above referred to, must hence be considered as again opened for discussion. My own analyses and experiments are as yet too indecisive to admit of forming any conclusions entitled to weight as to the probable constitution of the mineral, but as opportunity offers they will be prosecuted, and extended to material from any other localities in this country or abroad that may become available, and will be published in detail at some future time.

Trifling amounts of rare earths other than thoria were found in the Glastonbury and Colorado specimens as well as in those from North Carolina.

## 7. Dumortierite from New York and Arizona. By J. Edward Whitfield.

In the November (1887) number of the American Journal of Science Dr. R. B. Riggs published some observations, including a chemical analysis, on a mineral found at Harlem, N. Y., and generally supposed to be indicolite. The notice led to correspondence between Mr. J. S. Diller and Prof. E. S. Dana, the latter identifying it as dumortierite.

The composition, as determined by Dr. Riggs, conformed to no known mineral, and he was justified in provisionally calling it a new boro-silicate, but on further examination by Mr. Diller of a somewhat larger amount of material it was found that the mineral was associated with tourmaline, which no doubt accounts for the results of the analysis.

It was decided to analyze another portion which was known to be purer than that examined by Dr. Riggs. This was done, and the following figures are the results obtained: $SiO_2$ 31.44 per cent.; $Al_2O_3$ 68.91 per cent., with the smallest trace of boric acid. Their quantities compare fairly well with the theoretical amounts necessary to satisfy M. Damour's formula $Al_8Si_3O_{18}$ for dumortierite.

At about the time this work was being done on the New York

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mineral, a small piece of rock from Clip, Arizona, was sent to the National Museum for identification. Prof. F. W. Clarke recognized it as a specimen of dumortierite accompanying quartz, and it was subjected to analysis to confirm his opinion. Following are the results of the examination:

| | Per cent. |
|---|---|
| $SiO_2$ | 31.52 |
| $Al_2O_3$ | 63.66 |
| CaO | none. |
| MgO | .52 |
| $Na_2O$ | .37 |
| $K_2O$ | .11 |
| $B_2O_3$ | 2.62 |
| Ignition | 1.34 |
| | 100.14 |

These figures show that the mineral was rather impure, and it was thought advisable to obtain, if possible, more of the mineral, and endeavor to separate it as far as possible from the accompanying rock. Mrs. C. A. Bidwell, the sender of the first specimen, kindly furnished quite an amount of much better material, in which the only mineral associated with the dumortierite was quartz.

As dumortierite is not acted upon by hydrofluoric acid, the rock was crushed to small particles and digested in this acid for a length of time sufficient to remove most of the quartz. The mass was then washed with water, dried, and any quartz that might remain was separated by Thoulet's solution. After thorough washing, the material was examined with the aid of the microscope and found to be free from gangue.

After being ground exceedingly fine and dried at 104° C. for about three hours, the material was analyzed with the following results:

| | Per cent. |
|---|---|
| $SiO_2$ | 27.99 |
| $Al_2O_3$ | 64.49 |
| $P_2O_5$ | .20 |
| CaO | none. |
| MgO | trace. |
| $B_2O_3$ | 4.95 |
| $H_2O$ | 1.72 |
| | 99.35 |

These figures show less impurity than the first specimen analyzed; but if dumortierite is a simple silicate of alumina as stated, by M. Damour[1] these results either do not uphold his conclusions or they show the material to be a mixture of dumortierite and some other compound.

If we assume the formula of M. Damour to be correct and estimate all the $SiO_2$ in the analysis as belonging to the formula $Al_8Si_3O_{18}$, then there will be left unaccounted for a small amount of $Al_2O_3$, $H_2O$ and

[1] Bull. de la Soc. Min. de France, vol. 4, p. 6.

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$B_2O_3$, and these are present in the proportions represented by the formula $AlB_3O_6,2H_2O$. If this mode of interpretation be correct, then the mineral from Arizona corresponds approximately to the formula,

$$3Al_8Si_3O_{18},$$
$$AlB_3O_6.2H_2O,$$

which requires $Al_2O_3$ 65.2 per cent., $SiO_2$ 27.6 per cent.; $B_2O_3$ 5.4 per cent.; $H_2O$ 1.8 per cent.; agreeing quite closely with the actual analysis. A borate of alumina corresponding to the above formula is, we believe, not actually known, and concerning its properties nothing can be predicated. If it exists, it is certainly remarkable that it should withstand the treatment with hydrofluoric acid which the Dumortierite received during the process of purification.

We are deeply indebted to Mrs. C. A. Bidwell for the supply of material for investigation, which at the cost of much personal labor she so liberally furnished.

## 8. Xanthitane from North Carolina. By L. G. Eakins.

Through the kindness of Mr. William Earl Hidden some fine specimens of xanthitane were obtained, the material coming from Green River, Henderson county, N. C. It was first described by C. U. Shepard in the American Journal of Science, 1856, vol. 22, p. 96.

The material I examined is evidently an alteration product of sphene, following the form very closely. It is light yellow, friable, and mixed with impurities which can not be removed, preventing the determination of whether or not it is a definite mineral; but it is interesting from the fact that it apparently represents a clay with the silica replaced by titanic oxide.

Specific gravity 2.941 at 24°. The air-dried material loses 6.02 per cent. of water at 100°. The following analysis is on material dried at 100°:

| | |
|---|---|
| $SiO_2$ | 1.76 |
| $TiO_2$ | 61.54 |
| $Al_2O_3$ | 17.59 |
| $Fe_2O_3$ | 4.46 |
| CaO | 0.90 |
| MgO | trace. |
| $P_2O_5$ | 4.17 |
| $H_2O$ | 9.92 |
| | 100.34 |

## 9. Triplite from the Black Hills, Dakota. By L. G. Eakins.

The material for this analysis was taken from a large specimen of several pounds weight, in the collection of the National Museum. It comes from a tin mine near Rapid City, S. Dak. In reality it probably

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represents a mixture, but in general appearance it seems to be fairly homogeneous, and in composition it approaches closely to triplite.

It is brown in color, varying from light to dark, and translucent in thin pieces. In getting material for analysis any visible impurity was carefully picked out.

The composition is as follows:

| | |
|---|---|
| $SiO_2$ | .43 |
| $Al_2O_3$ | 8.74 |
| $Fe_2O_3$ | 2.36 |
| FeO | 1.97 |
| MnO | 29.13 |
| CaO | 6,72 |
| MgO | trace. |
| $K_2O$ | trace. |
| $Na_2O$ | 5.25 |
| $Li_2O$ | .13 |
| $P_2O_5$ | 39.68 |
| $H_2O$ | 3.67 |
| F | 2.35 |
| Cl | .25 |
| $CO_2$ | .26 |
| | 100.94 |
| Less O | 1.05 |
| | 99.89 |

## 10. KAOLIN FROM THE WATERFALL MINE, GUNNISON COUNTY, COLO. BY L. G. EAKINS.

This mineral occurs in a large mass, filling a cavern which has been opened for mining purposes in Redwell Basin, Gunnison county, Colo. It is especially interesting on account of being the containing mass of aggregates of galena and pyrite crystals which are scattered irregularly through it.

It is very fine and white, and on slightly rubbing up with water the material as it comes from the mine it can easily be floated off in a pure condition.

The analysis is as follows:

| | |
|---|---|
| $SiO_2$ | 47.28 |
| $Al_2O_3$ | 36.19 |
| $Fe_2O_3$ | trace. |
| CaO | .42 |
| MgO | trace. |
| $K_2O$ | 5.74 |
| $Na_2O$ | .51 |
| $H_2O$ | 8.72 |
| $P_2O_5$ | .57 |
| | 99.43 |

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## 11. Native Gold from Persia. By Charles Catlett.

The sample of gold, inclosing quartz, was submitted for assay through the State Department by the American minister to Persia, and was the property of the Persian Government. The specimen was of unusual interest as coming from a region so little known mineralogically. The native gold, which was of very light color, was analyzed with the following results:

| | |
|---|---|
| Au | 93.24 |
| Ag | 6.65 |
| Fe | .11 |
| Cu | none. |
| | 100.00 |

## 12. Pyroxene and Serpentine from Montville, N. J. By Charles Catlett.

The series in question was collected by Mr. G. P. Merrill, of the National Museum, and submitted to this laboratory for analysis. It consisted of a dark gray, and a white pyroxene (A and B), and a dark and a light serpentine (C and D), resulting from their respective alteration. An alteration product (E) closely related to the others was analyzed at the same time.

| | A. | B. | C. | D. | E. |
|---|---|---|---|---|---|
| $SiO_2$ | 51.45 | 48.17 | 40.23 | 42.38 | 4.32 |
| Ignition | 1.08 | *.12 | 14.24 | 14.12 | *1.26 |
| CaO | 24.02 | 21.96 | trace. | ..... | ..... |
| $CaCO_3$ | ..... | 10.44 | ..... | ..... | 87.75 |
| MgO | 18.43 | 17.61 | 39.46 | 42.14 | 4.07 |
| $MgCO_3$ | ..... | .71 | ..... | ..... | 1.67 |
| $Al_2O_3$ | 2.94 | .52 | 2.18 | .07 | .10 |
| $Fe_2O_3$ | 1.06 | .18 | 4.02 | .97 | |
| FeO | .96 | .24 | trace. | .17 | ..... |
| MnO | trace. | ..... | ..... | ..... | ..... |
| $SO_3$ | trace. | trace. | ..... | ..... | .13 |
| $K_2O$ | undet. | undet. | undet. | undet. | .12 |
| $Na_2O$ | undet. | undet. | undet. | undet. | .28 |
| | 99.94 | 99.95 | 100.13 | 99.85 | 99.70 |

* $H_2O$.

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## THE SUBSIDENCE OF FINE SOLID PARTICLES IN LIQUIDS.

[Second Paper.]

By CARL BARUS.

(1) In my earlier work I endeavored to analyze the phenomenon of sedimentation into parts such that the conditions under which subsidence is to be explained from a chemical, or from a physical point of view, may be better discernible.[1] To do this I first considered the question in its purely mechanical aspects.[2] If $P$ is the resistance encountered by a solid spherule of radius $r$, moving through a viscous liquid at a rate $x$, and if $k$ be the frictional coefficient, then $P=6\pi krx$. Again, the effective part of the weight of the particle is $P'=\frac{4}{3}\pi r^3(\rho-\rho')g$, where $g$ is the acceleration of gravity and $\rho$ and $\rho'$ the density of the solid particle and the liquid, respectively. In case of steady motion $P=P'$. Hence

$$x=\frac{2}{9k}r^2(\rho-\rho')g \quad \ldots\ldots\ldots \quad (1)$$

In any given case of thoroughly triturated material, the particles vary in size from a very small to a relatively large value; but by far the greater number approach a certain mean figure and dimension. An example of this condition of things may be formulated. To avoid mathematical entanglement I will select

$$y=ax^{\frac{3}{2}}e^{-x^2} \quad \ldots\ldots\ldots\ldots \quad (2)$$

where $y$ is the probable occurrence of the rate of subsidence $x$. If now the turbidity of the liquid (avoiding optical considerations) be

[1] The present article, being a continuation of Bull. U. S. G. S., No. 36, 1886, is largely based on the experimental evidence there tabulated. Mr. William Durham (Chem. News, vol. 30, 1874, p. 57; *id.*, vol. 37, 1878, p. 47) was the first to give an incentive to this class of experiments. Much of our knowledge of the effect of precipitants is due to him. Moreover, the theoretical views at which he ultimately arrives may be regarded as a definite point of departure. In this country, Prof. T. S. Hunt (Proc. Boston Soc. Nat. Hist., Feb., 1874), Prof. W. H. Brewer (National Acad. Sc. 1883; American Journ. Sci., series 3, vol. 29, 1885, p. 1), and Prof. C. R. Stuntz (Cincinnati Soc. Nat. Hist., Feb., 1886), have occupied themselves with similar work. Professor Stuntz's paper contains further references among others to Waldie's results (Journal Asiatic Soc., Bengal, 1873; Chem. News, 1873). Meanwhile Mr. William Hallock has made experiments on the subsidence of lamp-black in connection with his work on the density of that substance. (Cf. Bull. U. S. G. S., No. 42, 1887, p. 132) I may add that my own experiments were suggested by Professor Brewer's memoir.

[2] Cf. Kirchhoff: Mathematische Physik, lecture 26, § 4, 1876.



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defined as the mass of solid material per unit of volume of liquid, then the degree of turbidity which the given $ydx$ particles add to the liquid is, caet. par., proportional to $r^3ydx$, where $r$ is the mean radius. Hence the turbidity $T$, at the outset of the experiment (immediately after shaking), is

$$T=T_0\int_0^\infty r^3ydx=T_0$$

where equations (1) and (2) have been incorporated.

If the plane at a depth, $d$, below the surface be regarded, then at a time, $t$, after shaking, the residual turbidity there is

$$T=T_0\int_0^{\frac{d}{t}} r^3ydx=T_0\left(1-e^{\frac{d^2}{t^2}}\left(1+\frac{d^2}{t^2}\right)\right) \quad . \quad . \quad . \quad . \quad . \quad (3)$$

This equation describes the observed occurrences fairly well. In proportion as the time of subsidence is greater, the tube shows opacity at the bottom, shading off gradually upward, through translucency, into clearness at the top. If, instead of equation (2), there be introduced the condition of a more abrupt maximum; if, in other words, the particles be very nearly of the same size, then subsidence must take place in unbroken column, capped by a plane surface which at the time zero coincided with the free surface of the liquid. Again, suppose one-half of the particles of this column differ in some way uniformly from the other half. Then at the outset there are two continuous columns coinciding, or, as it were, interpenetrating throughout their extent. But the rate of subsidence of these two columns is necessarily different, since the particles, each for each, differ in density, radius, and frictional qualities by given fixed amounts. Hence the two surfaces of demarkation, which at the time zero coincided with the free surface. In general, if there be $n$ groups of particles uniformly distributed, then at the time zero $n$ continuous columns interpenetrate and coincide throughout their extent. At the time $t$, the free surface will be represented by $n$ consecutive surfaces of demarkation, below it, each of which caps a column, the particles of which form a distinct group. This phenomenon is Professor Brewer's stratified subsidence. In the case of particles which have undergone an earlier fractionated sedimentation, either in nature or in the arts, the occurrence of groups possessing the distinctive characteristics here discussed is not improbable. On the other hand, when during subsidence the surfaces of demarkation follow each other in regular succession, one is tempted to look for something more than an adventitious cause for the phenomenon. An orderly arrangement of groups of particles, might for instance, indicate successive stages of hydration. (Cf. § 6.) In case of stratified subsidence it is convenient to speak of orders of surfaces, numbering them from the top downward. It is not uncommon to observe seven or even ten consecutive orders.

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(2) With these deductions as a point of departure, I then attempted to find relations between rates of subsidence, the viscous and capillary properties of the liquid, and its electrical behavior under analogous conditions of concentration and of temperature. This general survey proved that the phenomenon of sedimentation is unique; that the frictional resistances encountered by the particles are apparently different from the viscosities of the liquids in which subsidence takes place; that many of the occurrences observed are closely allied to the electrolytic and the capillary properties of this liquid. Finally, utilizing Professor Brewer's stratified subsidence, which I obtained very clearly with certain kinds of tripoli, I commenced a series of more rigorously quantitative measurements, showing that, caet. par., rate of subsidence is primarily dependent on the turbidity of the mixture.

In my experiments with tripoli, the observed rates of subsidence ($^{cm}/(sec \times 10^6)$) in ether, alcohol, water, glycerine, were 7500, 1300, 3, 0.9, respectively; but, owing to the difference in character of the divers precipitates, these figures have no further signification than to emphasize the said difference in character. (Cf. §§ 5, 6.) Let water and ether be mixed so that there shall be equal bulks of etherized water below and aqueous ether above, and then let the dust (bole) be added. If now the mixture is violently shaken and then allowed to subside, the ether is washed clean of particles in a few minutes, whereas the sediments remain suspended in the water for weeks and even months. Here, however, the separation and subsidence are promoted by the surface energy of water. On the other hand, if dry tripoli be added to ether dried over $CaCl_2$, in a test tube, and if the tube be held obliquely after shaking, subsidence is so rapid that the upward current of ether along the upper line of the tube is almost tempestuous.

The close relation of the present phenomena to electrolytic phenomena appears at once by observing that so little as a single molecule of HCl (for instance) added to 10,000 or even to 50,000 molecules of $H_2O$, produces appreciable increase of the rate of subsidence. Remembering that the arrangement is in three dimensions, and supposing the molecule HCl as large as the molecule[1] $H_2O$, the effect of the molecule HCl must be appreciated at a distance of at least 30 times its own radius, and extend much beyond this asymptotically. Quincke's radius of capillary attraction, $.000005^{cm}$, being about 100 times the molecular radius $H^2O$, it appears that the striking effect of the molecule HCl in accelerating subsidence is not an abnormal occurrence, at least when considered physically. Other points of view are given in the Bulletin.

(3) To account for these phenomena as a whole, Mr. Durham in his second paper (l. c.) proposes a hypothesis in virtue of which the scope of the action of affinity is enlarged, and suspension regarded as the lower limit of solution. This view is fast gaining ground; nevertheless,

[1] The estimated diameter of $H_2O$, distance between centers of adjacent molecules $=40/10^{9cm}$. Kohlrausch. Wied. Ann., vol. 6, 1819, p. 209.

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without concise experimental reference to the density and size of the solid particles, and the viscosity of the liquid, Mr. Durham's explanation contains no sufficient reason for the observed suspension, nor for changes of rate of subsidence. Prof. Brewer's ingenious hypothesis of colloidal hydrates, so constituted that the particles may ultimately swell up and float, something like gelatinous silica, or even like starch grains, is more direct; and before further reasons of the cause of suspension are sought, the validity of this inference must be tested. This test is feasible, I think. If the phenomenal difference of rate with which the same particles subside in water and in ether is due to volume changes of the particles, then a marked difference in the density of the sediment (clay or tripoli) in water and in ether, respectively, must be experimentally demonstrable. Cf. Equation (1). I made these experiments with both solids, using two nearly identical density flasks, one for water and the other for ether, in the usual way. The powders were sampled and dried at 200° in an air bath, for half a day, transferred to the pyenometers, dried and weighed when cold. They were then left in a desiccator for 18 hours and again weighed; and finally dried in vacuo, and weighed. The results throughout were satisfactorily constant. By aid of an apparatus specially devised for the purpose, the two flasks were once more thoroughly exhausted (mercury air-pump), and then filled with water and with ether, respectively, in vacuo, over sulphuric acid. In both cases (experiments made consecutively) the vacuum ebullition was kept up for some time to give full assurance of the expulsion of air, etc. The density of the ether had been previously determined by the same flasks, once for each experiment.

I thus obtained for tripoli

$$\text{In water, density} = \Delta_w = 2.672,$$
$$\text{In ether, density} = \Delta_e = 2.697.$$

Again I obtained for white bole

$$\text{In water, } \Delta_w = 2.639,$$
$$\text{In ether, } \Delta_e = 2.663.$$

The manipulation being somewhat difficult, the observed differences of $\Delta_w$ and $\Delta_e$ are no larger than the many sources of error led me to anticipate, particularly in view of the fact that the two samples, for ether and for water, may not have been absolutely identical. The concentrated ether used was the same commercial reagent with which I obtained the subsidence phenomena. In consequence of the high but normal values of both $\Delta_w$ and $\Delta_e$, I saw no need of specially purifying it. I add finally that after calcination the dry tripoli lost 1.2 per cent. in weight, and the dry bole about 11.4 per cent. In both cases this is probably water of constitution, the elimination of which was of course not permissible. It is well to note that in spite of differences of chemical composition, bole particles are about equally well suspended before and after calcination, and the phenomena with ether dried over $CaCl_2$ are identical with the above.

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(4) These results show that the densities in the two cases (sediment in water and in ether respectively) are not essentially different. Moreover, the density of tripoli is so near that of quartz, and the density of bole so near that of kaolinite, as to leave the hydration hypothesis very seriously in the lurch, so far as favorable evidence is concerned. It is improbable that the addition of water to the dry powder is accompanied by sufficiently marked volume changes; it is certain that the enormous variation of rates of subsidence actually observed, when the particles descend in water, in solutions, and in ether, must be referred to some general cause apart from the density of the particles and the viscosity of the liquids.

(5) This premised, the explanation of sedimentation may, I think, be satisfactorily based on the following principle: If particles of a comminuted solid are shaken up in a liquid, the distribution of parts after shaking will take place in such a way that the potential energy of the system of solid particles and liquid, at every stage of subsidence, is the minimum compatible with the given conditions. In the case of solid particles and pure water the configuration answering these conditions is schematically

Particle, water....particle, water.

In the case of solid particles and ether, or of solid particles and solutions, this configuration is schematically

Particle, particle....ether, ether.

For the truth of this inference, my paper contains abundant experimental evidence. The principle asserts that in case of water the sediment is graded and the suspended material granular, whereas in ether the sediment is apparently homogeneous, as I found; that the bulk of sediment is necessarily less in water than in ether, being compact in the first instance and of a microscopically arched or castellated internal structure, in the second instance, as I found; that the effect of a precipitant is particularly marked when the mixture is densely turbid with relatively coarse particles, as I found; that, finally, the phenomenon of sedimentation must be of a distinct and special kind, and by no means the immediate converse of capillary viscous transpiration. The inferences are thus based on equation (1) above, and follow at once when $k$ and $\rho$ are constant. In the Bulletin I computed the relative size (radii) of the particles of tripoli subsiding in water, alcohol, ether, to be 1, 19, and 24, respectively.[1] It is exceedingly curious to note in case of water,

[1] This is the first hypothesis developed in detail in Bull. U. S. Geol. Survey, No. 36, pp. 34, 35, 37. In a recalculation since made with more accurate value of $k$ (water 0° to 100°, Slotte's data, in Wied. Ann. vol. 20, 1883, p. 262; ethyl and methyl alcohol, Graham's data in Phil. Mag. (4), vol. 24, 1861, p. 238; ether datum from Landolt and Boernstein's tables, p. 153; glycerine $\eta=10.0$g cm.$^{-1}$ sec.$^{-1}$, estimated roughly), the radii of the particles in water, ethyl alcohol, methyl alcohol, ether and glycerine are found to be r=0.000009$^{cm}$, 0.00019$^{cm}$, 0.00018$^{cm}$, 0.00020$^{cm}$ and 0.00005$^{cm}$, respectively. In case of bole suspended in water at 15° and at 100°, the radii were approximately $<$0.000010$^{cm}$ and$>$ 0.000020$^{cm}$, respectively. Section 6

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despite the phenomenally large surface energy of the liquid, the subsidence takes place in such a way that for a given mass of suspended sediment the surfaces of separation are a maximum. On the other hand, in case of subsidence in ether, or in salt solutions, the solid particles behave much like the capillary spherules of a heavy liquid shaken up in a lighter liquid with which it does not mix. In other words, the tendency is to reduce surfaces of separation to the least possible value, large particles growing in mass and bulk mechanically, at the expense of the smaller particles. Finally it is clear that the condition of stratified sedimentation is very slow subsidence of a granular precipitate.

(6) The experimental evidence adduced bears directly on the size of the particles of any precipitate. A given mass of small solid particles presupposed, the observations of the foregoing paragraphs make it probable that the potential energy of the system of solid particles and liquid increases with the radius of the particle. These observations also show that the potential energy of the system of solid particles alone decreases as the size of the particles increases, a state of things due both to the immediate action between solid particles and probably also to the surface energy of the liquid in which suspension takes place. Under these conflicting conditions it is probable that there is a critical shell within which the energy solid-liquid decreases less rapidly than the energy solid-solid; and beyond which shell the energy solid liquid increases more rapidly than the energy solid-solid. This critical shell being compatible with the conditions of minimum potential energy of the subsiding system, as a whole, is the size of the precipitated particles; for any change of the radius of a particle bounded by the critical shell, implies an expenditure of work, which under the usual conditions of subsidence is not available.

(7) I have finally to endeavor to assign some value to the radius of the critical shell for the case of the above water suspensions. In my experiments with tripoli, rates of subsidence, $x$ in cm$/$(sec$\times 10^6$), varied from $x=1$ to $x=20$, according as higher orders of surfaces or turbidities of lower degree were chosen. Taking the more usual value $x=3$, the radius of the particles subsiding was probably not less than 400 times the molecular radius of water. The bole particles under analogous conditions of suspension in $H_2O$, were smaller, probably only 100 water radii. In Professor Brewer's indefinitely suspended clays, the limit of comminution can not be estimated at all, except perhaps from purely optical consideration.[1] Whether in this extreme case colloidal hydra-

points out, that whereas these dimensions may be called in question when considered absolutely, the relative values of radius are probably true.

The fact that particles so extremely light descend at all is a most striking result, showing the extreme delicacy of these experiments. In case of tripoli-water, for instance, the estimated weight of particles is only $1/10^{11}$ milligram. Being invisible microscopically it must weigh less than $1/10^{10}$ milligram.

[1] The optical properties of light reflected from particles small in comparison with the wave length of light are discussed by Stokes (Phil. Trans., 1852, p. 530). How large a particle may be without interfering with optical clearness, I can not say.

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tion with concomitant volume changes is still demonstrably absent, remains to be seen. To test it, a sufficient quantity of the extremely fine material would have to be collected and dried by low temperature evaporation, an excessively tedious task.

Again, in Bulletin No. 35, p. 21, I point out at some length that "when the particles decrease (in size) from some estimable mean value indefinitely," liquid viscosity, being at least partially, if not largely kinetic in character, can no longer be considered constant; that therefore a particle may descend, or in other words the continuous and constant action of gravity produce an effect even when the weight of the particle is below the mean or physically measurable value of the friction encountered; that the limits of time-variation of viscosity will increase as the radius of the circumscribed space decreases. In such a case the particle to be stationary must weigh less than the lower limit of the variable viscosity—a quantity which may reasonably be conceived to approach zero very nearly. I carried these inferences one step further by supposing, rationally I think, that the limits within which this *elementary* viscosity (say) varies, will increase with the degree of molecular agitation of the liquid. On the basis of this postulate I then endeavored to explain sedimentation kinetically, both in its relation to temperature and the effect of precipitants.

One point which antagonizes this hypothesis in part must not be lost sight of. Two or more particles sufficiently near together tend to screen each other, and, receiving impact mainly on their outer surfaces, will be held in permanent coherence so long as the conditions of pronounced molecular agitation last. This is observed to some extent in solution suspensions, ether suspensions, and in water suspensions at high temperatures (100°). There is therefore some difficulty in preserving the granular state (Bull. 36, p. 38).

To pass judgment on the validity of such an explanation, it is necessary to have in hand better statistics of the size of the particles relatively to the water molecules than are now available. Indeed whether the liquid water molecule is simply $H_2O$ and not some more complex form can not at the present state of science be decided. Inasmuch as the particles in pure water are individualized and granular, it is apparently at once permissible to infer the size of the particles from the observed rates of subsidence. But my observations show that the said rates decrease in marked degree with the turbidity of the mixture. Hence the known formulæ for a single particle are not rigorously applicable though it can not be asserted whether the cause of discrepancy is physical or mathematical in kind. It follows that special deductions must be made for stated groups of particles before an estimate of their mean size can be fairly obtained.



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## A NEW METHOD OF MAKING ALLOYS.[1]

By William Hallock.

While occupied with a careful study of an article by W. Spring[2] on the production of Wood's alloy, and seeking the forces possibly brought to bear in his experiments, the following explanation occurred to me, and was subsequently verified by critical experiments. The method of production used by Mr. Spring was to mix filings of the four metals in the proper proportions, subject the mass to a pressure of 6,000 atmospheres, file up the block thus produced and compress it a second time, obtaining as an end result a block of Wood's alloy.

Now, if at any time during the various operations, be it the first compression, the subsequent filing, or the second compression, or if anywhere in the whole mass, the original metals came in contact all together, then at that point we should have a particle, a molecule as it were, of Wood's alloy. If thereafter the temperature ever rose to 70° C., that particle would melt and dissolve down its immediate neighbors until finally the whole mass was liquefied and converted into a homogeneous mass of alloy. Without waiting to consider how improbable it was that the three or four metals could be brought simultaneously into perfect enough contact to act as a real alloy, I tried the experiment and it proved an easy success.

The metals were filed to fine grains and mixed in the proper proportions, one part cadmium, one part tin, two parts lead, and four parts bismuth. A glass tube of $5^{mm}$ inner diameter and $70^{mm}$ length, sealed at one end, served as containing vessel. About 6 grams of the mixed filings were placed in this tube and packed down, an iron wire $3^{mm}$ diameter, held between the thumb and finger, being used as a packer; which certainly eliminated the possibility of any considerable pressure. The tube was thereupon so placed upon the water-bath that the sealed end containing the metals projected downward into the boiling water. In this way the filings remained dry and were kept at a temperature of 98° to 100° C. After remaining in this position for eighteen hours (over night) the filings showed signs of sinking together, which would

[1] Read before the Philosophical Society of Washington, D. C., at the meeting of February 18, 1888.

[2] W. Spring: Ber. der Chem. Gesell., vol. 15, 1882, pp. 595–597.



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indicate a beginning of the reaction. The tube was jarred upon the table to assist the condensation and again placed on the bath. Two hours later the tube contained a *homogeneous liquid globule of Wood's alloy.* The experiment was repeated, using two larger tubes, into which the metals were packed with a lead pencil, and producing some 30 grams of alloy. Of course when the operation is once started there is no limit to the quantity which can be produced. One tube remained on the water-bath over a week without signs of a solution and yet finally dissolved.

In further application of the same principle lead and tin were melted together at 190° to 200° C. by simply laying a piece of tin upon a carefully cleaned piece of lead and placing the whole in an air-bath at 190° C. A few hours suffice for this experiment. The melting points of the above metals are—cadmium 315° C., tin 230° C., bismuth 267° C., lead 325° C. Potassium and sodium were also used, melting at 62° 5′ C. and 95° 6′ C. respectively.

A very interesting and striking experiment is the production of the alloy of equal parts of potassium and sodium, which is liquid at temperatures above 6° C. Pieces of the two metals are simply placed with freshly cut surfaces in contact and slightly pressed together; in a few seconds the liquid alloy, which resembles mercury, is visible in drops around the contact surface, and an hour or two suffices to produce several cubic centimeters of the fluid.

It is my intention in the near future to follow up these observations by a series of experiments intended to establish and extend the principle here illustrated. The heat phenomena which doubtless accompany these reactions will also be investigated. Possibly also some electrical manifestations may be discovered, and perhaps some facts bearing upon the origin of contact electricity may be developed. In the mean time I would propose the following law: An alloy can be produced out of its original constituents without considerable pressure if the temperature be above the melting point of the alloy, even though it be far below the melting point of the most easily fusible constituent.

Probably this law will also be found applicable wherever under the existing circumstances the product is a liquid, even though the original substances be solids.

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## MISCELLANEOUS ANALYSES.

### ROCKS COLLECTED BY R. D. IRVING.

A. Separations from the gabbro of Ashland County, Wis.: 1, Feldspar; 2, diallage; 3, magnetite, partial.

[Analyses by W. F. Hillebrand.]

| | No. 1. | No. 2. | No. 3. |
|---|---|---|---|
| $H_2O$ | .23 | .33 | ..... |
| $SiO_2$ | 53.30 | 49.80 | ..... |
| $TiO_2$ | trace. | 1.29 | 8.47 |
| $P_2O_5$ | trace. | trace. | ..... |
| $Al_2O_3$ | 29.03 | 2.86 | ..... |
| $Fe_2O_3$ | .55 | 2.48 | 50.29 |
| FeO | .23 | 10.82 | 30.70 |
| MnO | none. | .37 | ..... |
| SrO, BaO | traces. | none. | ..... |
| CaO | 11.40 | 16.50 | ..... |
| MgO | .13 | 15.33 | ..... |
| $K_2O$ | .40 | .12 | ..... |
| $Na_2O$ | 4.87 | .51 | ..... |
| $Li_2O$ | none. | trace? | ..... |
| | 100.14 | 100.41 | 89.46 |

B. Garnet, separated from the garnetiferous actinolite schist of Penokee Gap, Wis.:

[Incomplete analysis on only 0.54 gram, by T. M. Chatard.]

| | |
|---|---|
| $SiO_2$ | 39.31 |
| $Al_2O_3$ | 12.86 |
| $Fe_2O_3$ (total iron) | 46.66 |
| MnO | 1.03 |
| CaO | 1.88 |
| MgO | 1.90 |
| | 103.64 |

The excess, 3.64, is oxygen added to ferrous iron. Correcting, we have approximately $Fe_2O_3$, 10.21; FeO, 32.81.

C. Limestones and iron carbonates: 1, Limestone, near Sunday Lake, Gogebic district, Mich.; 2, Limestone, Penokee region, Wis.; 3,



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cherty iron carbonate, Gogebic district; 4, iron carbonate, outlet of Sunday Lake; 5, iron carbonate, Palms mine, Gogebic district.

[Analyses by W. F. Hillebrand.]

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. |
|---|---|---|---|---|---|
| $H_2O$ | .30 | .27 | .54 | .68 | .60 |
| $CO_2$ | 45.31 | 46.27 | 41.10 | 25.21 | 19.24 |
| $SiO_2$ | 3.07 | .63 | 3.16 | 28.86 | 46.47 |
| $TiO_2$ | ..... | ..... | ..... | ..20 | .10 |
| $P_2O_5$ | ..... | ..... | .06 | trace. | trace. |
| Cl | trace. | trace. | trace. | ..... | (?) |
| $Al_2O_3$ | ..... | ..... | .08 | 1.29 | .70 |
| $Fe_2O_3$ | .09 | .03 | .93 | 1.01 | .86 |
| FeO | .86 | .75 | 15.18 | 37.37 | 28.57 |
| MnO | .15 | .08 | 1.15 | .97 | .40 |
| CaO | 29.72 | 30.94 | 26.65 | .74 | .49 |
| MgO | 19.95 | 20.68 | 11.01 | 3.64 | 2.30 |
| $FeS_2$ | ..... | ..... | .34 | ..... | ..... |
| Organic matter | ..... | ..... | ..... | undet. | undet. |
| | 99.45 | 99.65 | 100.20 | 99.97 | 99.73 |

(Same series continued): 6, Iron carbonate, Miner and Wells' option, Sec. 13, T. 47 N., R. 46 W., Michigan; 7, "iron carbonate," bed of Slate Creek, Huron Bay slate quarries, Michigan; 8, iron carbonate, northwest ¼ Sec. 18, T. 47, R. 45 W., Minnesota; 9, slaty rock, supposed iron carbonate, bed of Cross River, near Gunflint Lake, Michigan.

[Analyses by T. M. Chatard.]

| | No. 6. | No. 7. | No. 8. | No. 9. |
|---|---|---|---|---|
| $H_2O$ | 1.71 | .25 | 1.52 | 1.99 |
| $CO_2$ | 17.72 | 39.68 | 22.44 | .41 |
| $SiO_2$ | 46.01 | 7.05 | 36.73 | 64.77 |
| $TiO_2$ | .12 | none? | .19 | .60 |
| $P_2O_5$ | .07 | .27 | .01 | .20 |
| $SO_3$ | .15 | .21 | .16 | .60 |
| $Al_2O_3$ | .83 | .48 | .38 | 14.45 |
| $Fe_2O_3$ | 1.35 | 1.33 | .98 | 1.84 |
| FeO | 26.07 | undet. | 34.81 | 4.54 |
| MnO | 2.04 | .19 | .52 | .11 |
| CaO | .63 | 50.08 | .48 | 2.33 |
| MgO | 2.86 | .57 | 2.74 | 2.34 |
| Alkalies | undet. | undet. | undet. | $K_2O$. 5.03<br>$Na_2O$. 1.37 |
| | 99.61 | 100.11 | 100.96 | 100.58 |

(Same series continued): 10, Iron carbonate, west end of Gunflint Lake, Minnesota; 11, iron carbonate, north side of lake; 12, limestone, east end of Ogiskemannissi Lake, Minnesota; 13, limestone, north side of Gunflint Lake, Canada.

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[Analyses by T. M. Chatard.]

| | No. 10. | No. 11. | No. 12. | No. 13. |
|---|---|---|---|---|
| $H_2O$ | 2.08 | 1.22 | 1.07 | .99 |
| $CO_2$ | 5.22 | 19.96 | 24.70 | 32.42 |
| $SiO_2$ | 58.23 | 46.46 | 41.99 | 23.90 |
| $TiO_2$ | trace? | trace? | trace? | none. |
| $P_2O_5$ | .03 | .13 | .05 | trace? |
| $SO_3$ | .19 | .14 | .32 | .17 |
| $Al_2O_3$ | .06 | .24 | 1.24 | .07 |
| $Fe_2O_3$ | 5.01 | .64 | .42 | .44 |
| FeO | 18.48 | 26.34 | 4.77 | 10.72 |
| MnO | .25 | .21 | .26 | .28 |
| CaO | .38 | 1.87 | 16.85 | 22.25 |
| MgO | 9.59 | 3.10 | 8.41 | 8.52 |
| Alkalies | undet. | undet. | undet. | undet. |
| | 99.52 | 100.31 | 100.08 | 99.76 |

## NOVACULITE FORM MARQUETTE, MICH.

[Collected by G. H. Williams; analyzed by W. F. Hillebrand.]

| | |
|---|---|
| $H_2O$ | 2.35 |
| $SiO_2$ | 76.99 |
| $P_2O_5$ | trace. |
| $Al_2O_3$ | 13.92 |
| $Fe_2O_3$ | .45 |
| FeO | .77 |
| MnO | trace. |
| CaO | .32 |
| MgO | 1.12 |
| $K_2O$ | 3.65 |
| $Na_2O$ | .56 |
| $Li_2O$ | trace. |
| | 100.13 |

## BRICK-CLAY FROM NEW ULM, MINN.

Color greenish-gray. Brick made from it is reddish-brown, strongly sintered, somewhat fractured. Received from Hon. John Lind.

[Analyzed by T. M. Chatard.]

| | |
|---|---|
| Ignition | 10.73 |
| $SiO_2$ | 61.32 |
| $TiO_2$ | .66 |
| $P_2O_5$ | .27 |
| $SO_3$ | .19 |
| $Al_2O_3$ | 12.27 |
| $Fe_2O_3$ | 3.62 |
| FeO | 4.18 |
| MnO | .27 |
| BaO | .05 |
| CaO | .99 |
| MgO | 1.76 |
| $K_2O$ | 3.59 |
| $Na_2O$ | .42 |
| | 100.32 |

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## ROCKS FROM MONTANA.

[Collected by A. C. Peale and G. P. Merrill.]

**A. From hills east of Fort Ellis: 1, Rock, analysis by T. M. Chatard; 2, ground mass; and 3, portion soluble in hydrochloric acid, analyzed by L. G. Eakins.**

| | A. 1. | A. 2. | A. 3. |
|---|---|---|---|
| $H_2O$ | 5.42 | 1.90 | ..... |
| $SiO_2$ | 46.90 | 65.23 | 20.88 |
| $TiO_2$ | .41 | ..... | ..... |
| $P_2O_5$ | .44 | ..... | ..... |
| $Al_2O_3$ | 10.17 | 17.48 | 3.89 |
| $Cr_2O_3$ | .33 | ..... | ..... |
| $Fe_2O_3$ | 1.22 | .98 | 2.21 |
| FeO | 5.17 | ..... | 4.28 |
| MnO | .10 | ..... | trace. |
| CaO | 6.20 | 3.08 | 1.01 |
| MgO | 20.98 | 2.02 | 16.44 |
| $K_2O$ | 2.04 | 4.63 | trace. |
| $Na_2O$ | 1.16 | 3.79 | trace. |
| Insoluble | ..... | ..... | 51.29 |
| | 100.54 | 99.11 | 100.00 |

**B. From hills north of Camp 6 (Peale), East Gallatin River.**

**C. Partial analysis of vein from rock north of East Gallatin River.**

[Analyses by L. G. Eakins.]

| | B. | C. |
|---|---|---|
| $H_2O$ | 4.14 | ..... |
| $SiO_2$ | 49.47 | 65.19 |
| $TiO_2$ | .21 | ..... |
| $P_2O_5$ | .37 | ..... |
| $CO_2$ | 3.31 | ..... |
| $Al_2O_3$ | 12.15 | 16.38 |
| $Cr_2O_3$ | trace | ..... |
| $Fe_2O_3$ | 1.93 | 2.31 |
| FeO | 4.07 | ..... |
| MnO | .10 | ..... |
| BaO | .03 | ..... |
| CaO | 9.30 | .56 |
| MgO | 10.86 | ..... |
| $K_2O$ | 2.42 | 8.09 |
| $Na_2O$ | 2.08 | 1.71 |
| | 100.44 | 94.24 |

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D. From Cottonwood Creek: 1, Rock, analysis by T. M. Chatard; 2, portion soluble in dilute hydrochloric acid, analysis by L. G. Eakins.

| | D. 1. | D. 2. |
|---|---|---|
| $H_2O$ | 3.19 | ..... |
| $SiO_2$ | 51.65 | 12.94 |
| $TiO_2$ | .55 | ..... |
| $P_2O_5$ | .21 | ..... |
| $SO_3$ | .19 | ..... |
| $Al_2O_3$ | 13.89 | 2.93 |
| $Cr_2O_3$ | .08 | ..... |
| $Fe_2O_3$ | 2.70 | 5.07 |
| FeO | 4.80 | |
| MnO | .15 | trace. |
| BaO | .19 | ..... |
| CaO | 4.07 | .96 |
| MgO | 11.56 | 8.28 |
| $K_2O$ | 4.15 | .33 |
| $Na_2O$ | 2.99 | .39 |
| | 100.37 | 30.90 |

E. Porphyrite, Cottonwood Creek: 1, Complete; 2, portion soluble in dilute hydrochloric acid.

[Analyses by L. G. Eakins.]

| | E. 1. | E. 2. |
|---|---|---|
| $H_2O$ | 2.68 | ..... |
| $SiO_2$ | 52.33 | 13.62 |
| $TiO_2$ | .14 | ..... |
| $P_2O_5$ | 1.02 | ..... |
| $Al_2O_3$ | 15.09 | 5.93 |
| $Fe_2O_3$ | 4.31 | ..... |
| FeO | 4.03 | ..... |
| MnO | .09 | ..... |
| BaO | .07 | ..... |
| CaO | 7.06 | ..... |
| MgO | 6.73 | ..... |
| $K_2O$ | 3.76 | .08 |
| $Na_2O$ | 3.14 | .78 |
| | 100.45 | 20.41 |

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F. and G. Two rocks from northwest of Cottonwood Creek.

[Partial analyses, as requested, by L. G. Eakins.]

| | F. | G. |
|---|---|---|
| $SiO_2$ | 62.98 | 54.29 |
| $Al_2O_3$ | 18.44 | 18.47 |
| $Fe_2O_3$ | 2.49 | 5.67 |
| CaO | 1.79 | 3.69 |
| MgO | ..... | 3.98 |
| $K_2O$ | 4.35 | 5.92 |
| $Na_2O$ | 5.58 | 4.13 |
| | 95.63 | 96.15 |

H. Eight carboniferous limestones. Analyses by C. Catlett: 1, north of East Gallatin River; 2, west of North Bowlder River; 3, 4, north of East Gallatin River; 5, west side of Bridger Range, base of carboniferous; 6, north of Gallatin River, middle formation; 7, 8, north of Gallatin River, upper formation.

| | H.1. | H.2. | H.3. | H.4. | H.5. | H.6. | H.7. | H.8. |
|---|---|---|---|---|---|---|---|---|
| $CaCO_3$ | 54.54 | 54.54 | 67.85 | 59.11 | 88.50 | 91.96 | 32.28 | 40.21 |
| $MgCO_3$ | 43.63 | 42.62 | 6.18 | 1.96 | .95 | 1.35 | 13.91 | 25.25 |
| $Fe_2O_3$, $Al_2O_3$ | .22 | .40 | 2.50 | 1.92 | .38 | .58 | .30 | 5.30 |
| Insoluble | .34 | 1.78 | 23.50 | 35.26 | 9.98 | 5.99 | 50.74 | 25.24 |
| Water, etc. | undet. | undet. | undet. | undet. | undet. | undet. | undet. | undet. |
| | 98.73 | 99.34 | 100.03 | 98.25 | 99.81 | 99.88 | 97.23 | 96.00 |

ERUPTIVE ROCK FROM THE HENRY MOUNTAINS, UTAH.

[Received from J. S. Diller; analyzed by R. B. Riggs.]

| | |
|---|---|
| $H_2O$ | .69 |
| $SiO_2$ | 63.16 |
| $TiO_2$ | .21 |
| $P_2O_5$ | .12 |
| $SO_3$ | trace. |
| $Al_2O_3$ | 17.21 |
| $Fe_2O_3$ | 2.43 |
| FeO | 2.30 |
| MnO | trace. |
| CaO | 6.27 |
| MgO | 1.27 |
| SrO | trace? |
| BaO | .09 |
| $Li_2O$ | trace |
| $Na_2O$ | 4.70 |
| $K_2O$ | 1.84 |
| | 100.29 |

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## ROCKS FROM NEW MEXICO.

[Collected by J. W. Powell; analyzed by L. G. Eakins.]

### A. Obsidian from Obsidian Hill Camp.

| | |
|---|---|
| $H_2O$ | .33 |
| $SiO_2$ | 76.20 |
| $TiO_2$ | trace. |
| $Al_2O_3$ | 13.17 |
| $Fe_2O_3$ | .34 |
| FeO | .73 |
| MnO | .10 |
| CaO | .42 |
| MgO | .19 |
| $K_2O$ | 4.46 |
| $Na_2O$ | 4.31 |
| | 100.25 |
| Specific gravity | 2.352, 23° 5′ |

### B, C, D, and E. Four basalts, Rio Grande Cañon.

| | B. | C. | D. | E. |
|---|---|---|---|---|
| $H_2O$ | .82 | .64 | 1.29 | .53 |
| $CO_2$ | trace. | .58 | .37 | ..... |
| $SiO_2$ | 52.27 | 51.57 | 52.37 | 52.38 |
| $TiO_2$ | 1.49 | 1.43 | 1.60 | 1.22 |
| $P_2O_5$ | ..... | ..... | ..... | .56 |
| Cl | trace. | ..... | trace. | ..... |
| $Al_2O_3$ | 17.68 | 17.72 | 17.01 | 18.79 |
| $Fe_2O_3$ | 2.51 | 6.24 | 1.44 | 2.88 |
| FeO | 5.00 | 1.78 | 5.89 | 4.90 |
| MnO | .23 | .45 | .32 | .18 |
| BaO | .06 | .16 | .06 | .11 |
| CaO | 8.39 | 8.82 | 7.59 | 7.70 |
| MgO | 6.05 | 4.91 | 6.86 | 4.91 |
| $K_2O$ | 1.58 | 1.99 | 1.59 | 1.76 |
| $Na_2O$ | 4.19 | 3.59 | 3.51 | 3.99 |
| | 100.27 | 99.88 | 99.90 | 99.91 |

## LAVAS FROM NEAR LASSEN PEAK, CALIFORNIA.

[Series collected by J. S. Diller.]

1. West end of Lake Bidwell.
2. Silver Lake.
3. Volcanic sand, half-mile northeast of Cinder Cone, 10 miles northeast of Lassen Peak.
4. Inclusion in lava of Cinder Cone.
5. Lava of volcanic bomb, from Cinder Cone.
6. One-third of a mile south of Cinder Cone, on border of lava field.
7. Lapilli from Cinder Cone.

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8. Timber line, west base of Lassen Peak.
9. Lava enveloping No. 8.
10. East end of Chaos, northwest base of Lassen Peak.
11. East end of Chaos, northwest base of Lassen Peak.
12. Two miles south of Luffan's Mountain, Llana County.
13. Two miles south of Luffan's Mountain, Llana County.
14. Northwest base of Luffan's Mountain, at base of high cliffs near Lassen Peak.
15. West side of old crater near Thumb, head of Mill Creek.
16. One mile southwest of Thumb, at head of Bailey Creek.
17. Lava resting on dacite, near west base of Lassen Peak.
18. One and one-half miles northeast of Clipper Mills, on tramway to Rock Creek, Shasta County.
19. West summit of Crater Mountain.
20. North slope of Crater Mountain.
21. Nodule from No. 20.
22. Near eastern end of rim, Crater Mountain.
23. South base of Burney Butte.
24. Cone at south base of Burney Butte.
25. Northwest summit in rim about the head of Burney Creek.

[Analysis 1 to 21 by W. F. Hillebrand; 22 to 25 by R. B. Riggs.]

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. | No. 7. | No. 8. |
|---|---|---|---|---|---|---|---|---|
| $H_2O$ | .42 | .86 | .26 | .68 | .30 | .28 | .27 | .91 |
| $SiO_2$ | 56.18 | 57.59 | 55.93 | 79.49 | 56.70 | 54.56 | 56.53 | 55.14 |
| $TiO_2$ | } | | | | .65 | .53 | .54 | .52 |
| $P_2O_5$ | } | | | | .20 | .18 | .15 | .18 |
| $Al_2O_3$ | 16.59 | 16.49 | 17.34 | 11.60 | 15.75 | 16.04 | 17.50 | 19.10 |
| $Cr_2O_3$ | ..... | ..... | ..... | ..... | trace. | trace. | trace. | none. |
| $Fe_2O_3$ | 1.51 | 1.22 | 1.50 | .33 | 1.29 | .95 | 1.35 | 6.16 |
| FeO | 5.51 | 4.89 | 5.20 | .49 | 5.32 | 6.07 | 5.03 | .54 |
| MnO | undet. | undet. | undet. | none. | .19 | .17 | .12 | .11 |
| BaO | (?) | (?) | (?) | (?) | .03 | .03 | trace. | trace. |
| SrO | (?) | (?) | (?) | (?) | trace. | trace. | (?) | .07 |
| CaO | 7.64 | 7.40 | 8.04 | 1.64 | 7.67 | 8.89 | 8.07 | 8.36 |
| MgO | 7.26 | 7.72 | 7.29 | .09 | 7.16 | 8.71 | 5.94 | 4.23 |
| $K_2O$ | 1.47 | .99 | 1.35 | 1.52 | 1.56 | 1.18 | 1.55 | 1.04 |
| $Na_2O$ | 3.58 | 3.62 | 3.32 | 4.04 | 3.36 | 3.05 | 3.51 | 3.71 |
| $Li_2O$ | (?) | (?) | (?) | (?) | trace. | trace. | trace. | trace. |
| | 100.16 | 100.78 | 100.23 | 99.88 | 100.18 | 100.64 | 100.56 | 100.07 |

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| | No. 9. | No. 10. | No. 11. | No. 12. | No. 13. | No. 14. | No. 15. | No. 16. |
|---|---|---|---|---|---|---|---|---|
| $H_2O$ | 1.37 | .74 | .77 | .55 | 1.09 | 1.09 | 1.03 | 1.04 |
| $SiO_2$ | 68.32 | 68.72 | 53.35 | 63.47 | 57.04 | 58.08 | 63.81 | 59.84 |
| $TiO_2$ | .31 | .31 | .56 | .37 | .47 | .44 | .38 | .57 |
| $P_2O_5$ | .12 | .09 | .10 | .13 | .08 | .16 | .10 | .19 |
| $Al_2O_3$ | 15.26 | 15.15 | 19.22 | 16.75 | 19.11 | 18.37 | 17.07 | 16.81 |
| $Cr_2O_3$ | none. | none. | none. | trace? | none. | none. | none. | trace? |
| $Fe_2O_3$ | 1.66 | 1.16 | 3.28 | 2.15 | 4.37 | 2.92 | 2.11 | 1.88 |
| FeO | 1.26 | 1.76 | 4.48 | 2.75 | 2.48 | 3.38 | 2.15 | 3.60 |
| MnO | .04 | .11 | .15 | .09 | .12 | .13 | .09 | .14 |
| BaO | .07 | .07 | (?) | .04 | trace? | .03 | .04 | .07 |
| SrO | trace. | .03 | .03 | .04 | .02 | .02 | .03 | .02 |
| CaO | 3.26 | 3.30 | 9.76 | 5.72 | 7.34 | 7.05 | 4.97 | 6.30 |
| MgO | 1.32 | 1.28 | 4.86 | 3.04 | 3.94 | 3,35 | 2.28 | 3.85 |
| $K_2O$ | 2.81 | 2.78 | .99 | 1.62 | 1.16 | 1.33 | 1.96 | 2.13 |
| $Na_2O$ | 4.27 | 4.26 | 2.89 | 3.94 | 3.48 | 3.66 | 4.08 | 3.63 |
| $Li_2O$ | trace. | trace. | trace. | trace. | trace. | trace. | trace. | trace. |
| | 100.07 | 99.76 | 100.44 | 100.66 | 100.70 | 100.01 | 100.10 | 100.07 |

| | No. 17. | No. 18 | No. 19. | No. 20. | No. 21. | No. 22. | No. 23. | No. 24. | No. 25. |
|---|---|---|---|---|---|---|---|---|---|
| $H_2O$ | .69 | .85 | .40 | .83 | .45 | 1.47 | 1.02 | .79 | .90 |
| $SiO_2$ | 56.51 | 74.60 | 68.12 | 61.17 | 53.85 | 52.95 | 62.44 | 52.63 | 60.04 |
| $TiO_2$ | .48 | .16 | .25 | .45 | .50 | .66 | .31 | .07 | .49 |
| $P_2O_5$ | .14 | .03 | .14 | .14 | .05 | trace. | .05 | .47 | .04 |
| $SO_3$ | ..... | ..... | ..... | ..... | ..... | trace. | trace. | trace. | trace. |
| $Al_2O_3$ | 18.10 | 13.41 | 16.24 | 17.74 | 18.53 | 18.25 | 16.30 | 17.62 | 17.43 |
| $Cr_2O_3$ | trace. | none. | none. | none. | trace. | ..... | ..... | ..... | ..... |
| $Fe_2O_3$ | 4.26 | 1.28 | 1.26 | 1.78 | 1.96 | 4.36 | 4.66 | 6.49 | 5.39 |
| FeO | 2.68 | .30 | 2.08 | 3.51 | 5.30 | 4.19 | 1.00 | 3.10 | .53 |
| MnO | .11 | .06 | .10 | .12 | .12 | .12 | Trace. | Trace. | .08 |
| BaO | .04 | .11 | .09 | .06 | .03 | .01 | .03 | .04 | .04 |
| SrO | .04 | none. | .02 | .04 | .04 | trace. | trace. | trace. | (?) |
| CaO | 8.15 | 1.08 | 3.80 | 5.90 | 9.66 | 8.73 | 6.22 | 8.62 | 6.65 |
| MgO | 4.52 | .26 | 1.35 | 2.76 | 5.88 | 4.93 | 2.65 | 5.64 | 3.51 |
| $K_2O$ | 1.15 | 4.50 | 2.54 | 1.71 | .74 | .77 | 2.25 | 1.73 | 1.24 |
| $Na_2O$ | 3.23 | 3.38 | 3.89 | 3.79 | 2.98 | 3.57 | 3.16 | 3.38 | 4.15 |
| $Li_2O$ | trace. | trace. | trace. | trace. | trace. | (?) | trace. | trace. | trace. |
| | 100.10 | 100.02 | 100.28 | 100.00 | 100.09 | 100.01 | 100.18 | 100.58 | 100.49 |

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### BASALT, ISLAND OF MYTILENE, ASIA MINOR.

[Collected by J. S. Diller; analyzed by T. M. Chatard.]

| | |
|---|---|
| $H_2O$ | 2.12 |
| $CO_2$ | 2.32 |
| $SiO_2$ | 56.58 |
| $TiO_2$ | .77 |
| $P_2O_5$ | .15 |
| $Al_2O_3$ | 14.88 |
| $Cr_2O_3$ | trace? |
| $Fe_2O_3$ | 2.31 |
| FeO | 3.04 |
| MnO | .16 |
| CaO | 8.69 |
| BaO | .07 |
| MgO | 3.76 |
| $K_2O$ | 2.18 |
| $Na_2O$ | 3.36 |
| | 100.39 |

### INCLUSION IN DIORITE FROM CRUGER'S STATION, NEAR PEEKSKILL, NEW YORK.

[Collected by G. H. Williams; analyzed by T. M. Chatard.]

| | |
|---|---|
| $H_2O$ | 4.61 |
| $SiO_2$ | 32.73 |
| $Al_2O_3$ | 46.58 |
| FeO | 5.12 |
| CaO | 11.04 |
| MgO | 1.00 |
| | 101.08 |

**Analysis made on only 0.4212 gramme. The mineral is margarite.**

### WHITE EARTH FROM TALLADEGA, ALA.

[Received from R. A. Moseley, jr.; analyzed by C. Catlett.

| | |
|---|---|
| Ignition | 1.94 |
| $SiO_2$ | 88.92 |
| $Al_2O_3$ | 7.47 |
| $Fe_2O_3$ | trace. |
| CaO | .18 |
| MgO | trace. |
| Alkalies | undet. |
| | 98.51 |

### SANDSTONE, BEREA, OHIO.

[Extensively quarried; analyzed by L. G. Eakins.]

| | |
|---|---|
| $H_2O$ | 1.19 |
| $SiO_2$ | 92.91 |
| $Al_2O_3$ | 3.78 |
| $Fe_2O_3$ | trace. |
| FeO | .91 |
| CaO | .31 |
| MgO | trace. |
| $K_2O$ | .61 |
| $Na_2O$ | .34 |
| | 100.05 |

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## KNOX DOLOMITE AND RESIDUAL CLAY.

[From Morrisville, Ala.; collected by I. C. Russell; analyzed by W. F. Hillebrand.]

| | Dolomite. | Clay. |
|---|---|---|
| $SiO_2$ | 3.24 | 55.42 |
| $Al_2O_3$ | .17 | 22.17 |
| $Fe_2O_3$ | .17 | 8.30 |
| FeO | .06 | trace. |
| CaO | 29.58 | .15 |
| MgO | 20.84 | 1.45 |
| $K_2O$ | ..... | 2.32 |
| $Na_2O$ | ..... | .17 |
| $H_2O$ | .30 | 9.86 |
| $CO_2$ | 45.54 | ..... |
| | 99.90 | 99.84 |

Of the water in the clay 2.10 per cent. was expelled at 100°.

## DOLOMITE FROM TUCKAHOE, WESTCHESTER COUNTY, N. Y.

The so-called "Tuckahoe marble." Extensively used as a building stone. White, highly crystalline.

[Analysis by W. F. Hillebrand.]

| | |
|---|---|
| Insoluble | 1.33 |
| $H_2O$ | .16 |
| $Fe_2O_3$ | .21 |
| CaO | 30.68 |
| MgO | 20.71 |
| $CO_2$ | 46.66 |
| | 99.75 |

Of the insoluble portion, 0.71 is silica. The iron is probably in part FeO.

## WHITE DOLOMITE MARBLE, COCKEYSVILLE, MD.

[Analysis by J. E. Whitfield.]

| | |
|---|---|
| $SiO_2$ | .44 |
| $Al_2O_3$ | 1.22 |
| FeO | trace. |
| CaO | 30.73 |
| MgO | 20.87 |
| $CO_2$ | 45.85 |
| Ignition | 1.22 |
| | 100.33 |

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### MARBLE FROM LOUISIANA.

From sections 19 and 20, T. 11 N., R. 3 W., five miles west of Winnfield. White, abundantly streaked with black. Received from the Supervising Architect of the Treasury.

[Analyzed by W. F. Hillebrand.]

| | |
|---|---|
| Insoluble | .65 |
| $H_2O$ | .13 |
| CaO | 55.01 |
| MgO | .60 |
| MnO | .10 |
| $CO_2$ | 43.43 |
| $SO_3$ | .27 |
| | 100.19 |

Traces of $Al_2O_3$, FeO, BaO, SrO, Cl, and organic matter.

### LIMESTONES FROM OHIO AND INDIANA.

Trenton limestones and Utica shales, collected by Professor Edward Orton in the course of an investigation of the oil and gas wells of the two States. Partial analyses, as called for.

A. From New Vienna, Ohio. Analyses by F. W. Clarke and R. B. Riggs, jointly. 1, 2, 3, Utica shales. 4, 5, 6, 7, Trenton limestones.

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. | No. 7. |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 15.24 | 27.16 | 27.40 | 36.20 | 37.64 | 42.04 | 30.82 |
| CaO | 17.11 | 33.43 | 35.27 | 46.16 | 49.04 | 51.18 | 23.00 |
| MgO | 1.25 | 2.16 | 1.32 | 1.52 | .58 | 3.08 | 12.90 |
| Insoluble | 60.17 | 29.51 | 25.80 | 8.47 | 9.93 | 2.12 | 28.43 |
| | 93.77 | 92.26 | 89.79 | 92.35 | 97.19 | 98.42 | 95.15 |

Iron and alumina present in the soluble portions.

B. Trenton limestones from Ohio. Analyses by Clarke and Riggs. 8, Arcadia, Hancock County; 9, Air-line Junction, Toledo; 10, gas rock, St. Henry's well, Mercer County; 11, oil-rock, Lima.

| | No. 8. | No. 9. | No. 10. | No. 11. |
|---|---|---|---|---|
| $CO_2$ | 38.54 | 42.84 | 40.96 | 43.92 |
| CaO | 47.17 | 30.64 | 50.34 | 32.24 |
| MgO | 2.59 | 18.05 | 2.86 | 17.36 |
| Insoluble | 8.56 | 3.52 | 2.27 | 1.64 |
| | 96.86 | 95.03 | 96.43 | 95.16 |

Iron and alumina present in the soluble portions.

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C. Seven Trenton limestones from Ohio. Analyzed by F. W. Clarke. 12, well No. 3, Bryan, gas rock; 13, McElree well, Kenton; 14, Huntsville; 15, Prospect; 16, Findlay street well, Dayton; 17, Xenia; 18, New Madison. Air-dried samples.

| | No. 12. | No. 13. | No. 14. | No. 15. | No. 16. | No. 17. | No. 18. |
|---|---|---|---|---|---|---|---|
| Insoluble... | 9.22 | 5.26 | 4.41 | 26.12 | 12.34 | 9.23 | 11.11 |
| $Fe_2O_3, Al_2O_3$. | 1.51 | 1.10 | 3.15 | 2.57 | .58 | .18 | 3.60 |
| $CaCO_3$..... | 49.00 | 84.32 | 57.23 | 66.02 | 82.36 | 86.54 | 64.91 |
| $MgCO_3$ ..... | 38.59 | 8.43 | 33.16 | 3.77 | 1.67 | 2.99 | 17.98 |
| | 98.32 | 99.11 | 97.95 | 98.48 | 96.95 | 98.94 | 97.60 |

In 14 and 18 ferrous carbonate was present.

D. Seventeen Trenton limestones from Ohio. Analyses by C. Catlett. 19, Air-line Junction, Toledo, depth 1,415 feet; 20, Upper Sandusky, city well No. 2; 21, Sandusky, depth 2,260 feet; 22, St. Mary's township, Auglaize County, gas-rock, Pauck well; 23, same locality, gas-rock, Bennett well; 24, Carey, first city well, depth about 1,350 feet; 25, Fort Recovery well No. 2, depth 1,065 feet; 26, Loomis and Nyman well, Tiffin, depth 1,470 to 1,481 feet; 27, Loomis and Nyman well, Tiffin, 1,488 to 1,494 feet; 28, gas-rock, Waggoner well, 6 miles west of Fremont; 29, London, depth 1,594 feet; 30, Celina, depth 1,112 feet; 31, Port Clinton, 1,660 to 1,700 feet; 32, Wauseon, 2,135 feet; 33, Napoleon, 1,830 feet; 34, oil rock, Kossuth, Allen County; 35, Franklin Township, Mercer County; Doenze's well, 1,107 feet.

| | No. 19. | No. 20. | No. 21. | No. 22. | No. 23. | No. 24. | No. 25. | No. 26. |
|---|---|---|---|---|---|---|---|---|
| Insoluble..... | 2.88 | 8.18 | 3.65 | 3.18 | 1.66 | 5.72 | 1.89 | 5.66 |
| $Fe_2O_3, Al_2O_3$..... | 8.68 | 4.31 | 4.58 | 3.12 | 2.48 | 3.08 | 1.57 | 4.86 |
| $CaCO_3$..... | 54.68 | 64.25 | 54.62 | 52.18 | 56.94 | 80.11 | 87.88 | 52.89 |
| $MgCO_3$..... | 25.73 | 15.93 | 33.67 | 38.42 | 35.55 | 8.09 | 7.43 | 33.46 |
| | 91.97 | 92.67 | 96.52 | 96.90 | 96.63 | 97.00 | 98.77 | 96.87 |

| | No. 27. | No. 28. | No. 29. | No. 30. | No. 31. | No. 32. | No. 33. | No. 34. | No. 35. |
|---|---|---|---|---|---|---|---|---|---|
| Insoluble ... | 9.88 | 5.22 | 15.90 | 2.95 | 7.46 | 18.24 | 2.66 | 1.08 | 3.68 |
| $Fe_2O_3, Al_2O_3$. | 1.46 | 6.32 | 1.84 | 2.95 | 4.16 | 7.28 | 2.14 | .66 | 8.38 |
| $CaCO_3$ ..... | 79.39 | 52.93 | 77.69 | 68.41 | 71.96 | 42.82 | 53.85 | 90.72 | 69.53 |
| $MgCO_3$ ..... | 6.20 | 32.75 | 1.89 | 24.18 | 14.34 | 28.11 | 37.33 | 6.69 | 10.68 |
| | 96.93 | 97.22 | 97.32 | 98.49 | 97.92 | 96.45 | 95.98 | 99.15 | 92.27 |



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E. Six Trenton limestones from Indiana. 1, Union City, 1,160 feet; 2, Bluffton, 1,062 to 1,067 feet; 3, Muncie, 920 feet; 4, Greensburg, 867 feet; 5, Vernon, 905 feet; 6, Wabash, about 900 feet.

[Analyses, 1, by F. W. Clarke; 2, 3, 4, 5, 6, by C. Catlett.]

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| Insoluble | 2.14 | 2.37 | 3.30 | .87 | 8.00 | 3.52 |
| $Fe_2O_3, Al_2O_3$ | 1.23 | 4.48 | 3.72 | .55 | .60 | 7.58 |
| $CaCO_3$ | 83.21 | 53.43 | 51.96 | 94.60 | 85.56 | 53.18 |
| $MgCO_3$ | 12.48 | 37.47 | 38.11 | .36 | trace. | 30.53 |
| | 99.06 | 97.75 | 97.09 | 96.38 | 94.16 | 94.81 |

## COQUINA, CORAL, CORAL ROCKS, ETC.

Collected by Professor N. S. Shaler in an investigation of coral reefs. Partial analyses, as called for.

A. Five coquina gravels from Florida; 1, 2, 3, 4, Tortugas; 5, Key West; samples air-dried.

[Analyses by F. W. Clarke.]

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. |
|---|---|---|---|---|---|
| Moisture | 3.27 | 3.57 | 5.12 | 3.07 | 3.19 |
| $CO_2$ | 41.46 | 41.07 | 40.39 | 41.53 | 41.58 |
| $SiO_2$ | .19 | .22 | .32 | .21 | .25 |
| $Al_2O_3, Fe_2O_3$ | .19 | .47 | .56 | .76 | .56 |
| CaO | 52.24 | 51.24 | 49.38 | 51.95 | 51.52 |
| MgO | 1.53 | 2.09 | 1.93 | 1.44 | 2.08 |
| | 98.88 | 98.66 | 97.70 | 98.96 | 99.18 |

Chlorides and sulphates present; phosphates not looked for.

B. Five coral and shell rocks from Florida; 6, near Fort Worth; 7, east side of St. John's River, near Seville; 8, corroded surface, Miami Reef; 9, near Oak Hill; 10, near Melborne.

[Analyses by F. W. Clarke.]

| | No. 6. | No. 7. | No. 8. | No. 9. | No. 10. |
|---|---|---|---|---|---|
| Moisture | 2.64 | 3.37 | 2.33 | 3.21 | 2.53 |
| $CO_2$ | 41.59 | 39.00 | 41.22 | 39.62 | 34.31 |
| $SiO_2$ | 2.94 | 8.50 | 2.99 | 5.87 | 17.83 |
| $Al_2O_3, Fe_2O_3$ | .23 | .73 | .65 | .95 | 1.18 |
| CaO | 51.51 | 47.29 | 51.22 | 50.34 | 43.85 |
| MgO | .71 | 1.51 | .06 | .37 | .26 |
| | 99.62 | 100.40 | 98.37 | 100.36 | 99.96 |

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C. Three coquinas from Florida; 11, coarse shell mass, Senote; 12, Salt Key Bank, coral rock; 13, Loggerhead Key.

[Analyses by L. G. Eakins.]

| | No. 11. | No. 12. | No. 13. |
|---|---|---|---|
| $H_2O$ | .11 | 1.13 | .81 |
| $CO_2$ | 43.89 | 43.87 | 43.71 |
| $SiO_2$ | .22 | .11 | .20 |
| $Al_2O_3, Fe_2O_3$ | .18 | .04 | .22 |
| CaO | 54.87 | 53.54 | 53.54 |
| MgO | .64 | .71 | .78 |
| | 99.91 | 99.40 | 99.26 |

D. Hammock clay, Melborne Creek, Florida.
E. Incrustation formed by evaporating waters, Everglades, Florida.
F. Ochreous deposit, Paint Rock, Dade County, Fla.

[Analyses by L. G. Eakins.]

| | D. | E. | F. |
|---|---|---|---|
| $H_2O$ | 23.61 | 19.56 | .31 |
| $CO_2$ | | 25.38 | 41.30 |
| Organic matter | | 19.68 | |
| $SiO_2$ | 38.04 | 1.59 | 1.32 |
| $Al_2O_3$ | 27.19 | 1.11 | .30 |
| $Fe_2O_3$ | | | 7.26 |
| FeO | | | .68 |
| MnO | | | trace. |
| CaO | 10.73 | 31.32 | 48.96 |
| MgO | .46 | .30 | .41 |
| Alkalies | undet. | undet. | |
| | 100.03 | 98.94 | 100.54 |

G. Phosphatic deposit, Island of Sombrero, West Indies.
H. Coralline bottom, Barbados.
I. Recent coral (Siderostria), Bermuda.

[Analyses by L. G. Eakins.]

| | G. | H. | I. |
|---|---|---|---|
| $H_2O$ | 3.05 | 2.73 | .54 |
| $CO_2$ | 3.47 | 43.40 | 43.74 |
| Cl | .66 | | |
| $P_2O_5$ | 39.12 | | |
| $SiO_2$ | .14 | 1.17 | .23 |
| $Al_2O_3$ | .29 | .31 | trace. |
| CaO | 51.15 | 46.45 | 55.16 |
| MgO | trace. | 5.15 | .20 |
| | 97.88 | 99.21 | 99.87 |

Alkalies not looked for.

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J. Fourteen coral rocks and one soil from the Hawaiian Islands. Analyzed by L. G. Eakins. 1, Laie; 2, 3, Kohuku Bluff; 4, Kohuku coral flat; 5, point near coral flat; 6, modern chalk, Oahu; 7, Diamond Head; 8, under lava, Honolulu; 9, near Pearl River lagoon; 10, old reef, Waialua; 11, Campbell's Ranch quarry, Waianea, Oahu; 12, Wailuku Bay; 13, Reef Three, Honolulu; 14, Prison Knoll, Honolulu; 15, Lava soil, Diamond Head.

[Analyses by L. G. Eakins.]

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. | No. 7. |
|---|---|---|---|---|---|---|---|
| $H_2O$ | 4.74 | .40 | .79 | .93 | .70 | 9.84 | 1.86 |
| $CO_2$ | 41.89 | 44.33 | 43.64 | 43.89 | 43.95 | 11.09 | 40.81 |
| $SiO_2$ | .35 | .19 | .67 | .25 | .26 | 33.25 | 2.97 |
| $Al_2O_3$ | .19 | .52 | .73 | .49 | .21 | 19.53 | 2.88 |
| $Fe_2O_3$ | | | | | | 10.71 | |
| CaO | 49.38 | 49.34 | 51.09 | 53.34 | 52.17 | 11.37 | 44.82 |
| MgO | 1.74 | 4.60 | 2.50 | .67 | 1.51 | 3.06 | 5.32 |
| | 98.29 | 99.38 | 99.42 | 99.57 | 98.80 | 98.85 | 98.66 |

| | No. 8. | No. 9. | No. 10. | No. 11. | No. 12. | No. 13. | No. 14. | No. 15. |
|---|---|---|---|---|---|---|---|---|
| $H_2O$ | 1.61 | 16.84 | 1.33 | .46 | 1.93 | 2.75 | 1.24 | 5.30 |
| $CO_2$ | 38.71 | none. | 42.68 | 43.96 | 42.80 | 40.59 | 42.81 | 11.41 |
| $P_2O_5$ | ..... | ..... | ..... | ..... | ..... | ..... | ..... | .24 |
| Cl | ..... | ..... | ..... | ..... | ..... | ..... | ..... | .91 |
| $SiO_2$ | 5.34 | 46.22 | 1.05 | .53 | .45 | 3.53 | .81 | 32.88 |
| $Al_2O_3$ | 5.11 | 19.16 | 1.26 | .62 | 1.82 | 2.26 | 1.19 | 12.02 |
| $Fe_2O_3$ | | 12.94 | | | | | | 11.52 |
| MnO | ..... | ..... | ..... | ..... | ..... | ..... | ..... | trace. |
| CaO | 42.24 | 1.72 | 51.07 | 50.69 | 50.54 | 46.52 | 52.67 | 12.20 |
| MgO | 5.95 | 2.24 | .11 | 2.98 | 1.83 | 2.45 | .42 | 11.70 |
| Alkalies | ..... | ..... | ..... | ..... | ..... | ..... | ..... | undet. |
| | 98.96 | 99.12 | 97.50 | 99.24 | 99.37 | 98.10 | 59.14 | 98.18 |

## IRON AND MANGANESE ORES.

Two iron ores and two ochres from the Lucas farm, Jefferson County, W. Va. Received from D. B. Lucas.

[Analyzed by C. Catlett.]

| | Ore. | | Ochre. | |
|---|---|---|---|---|
| | A. | B. | C. | D. |
| $SiO_2$ | 1.18 | 4.03 | 92.07 | 93.57 |
| Fe | 58.72 | 59.31 | 2.72 | 2.24 |
| Mn | none. | none. | undet. | undet. |
| P | .075 | trace. | undet. | undet. |
| S | .293 | trace. | undet. | undet. |

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Iron ore, Little's ore bank, Jefferson County, W. Va., and Hostler's ore bank, same county. From D. B. Lucas.

[Examined by C. Catlett.]

| | Little's. | Hostler's. |
|---|---|---|
| $SiO_2$ | 55.67 | 67.34 |
| Fe | 23.21 | 22.73 |

Also from D. B. Lucas, iron ore from Cool Spring ore bank, Clarke County, Va., and from Bear Pond, top of Blue Ridge, Va.

[Analyses by C. Catlett.]

| | Cool Spring. | Bear Pond. |
|---|---|---|
| $SiO_2$ | 29.63 | 7.11 |
| Fe | 36.50 | 48.24 |
| Mn | trace. | 1.625 |
| P | .175 | .941 |
| S | .232 | .156 |

Three manganese ores, from Elkton, Rockingham County, Va. Received from C. E. Creecy.

[Analyzed by C. Catlett.]

| | A. | B. | C. |
|---|---|---|---|
| Mn | 43.94 | 49.66 | 48.75 |
| $SiO_2$ | 15.88 | 1.80 | 15.08 |
| Fe | 3.43 | 8.53 | 2.79 |
| P | .166 | .076 | .085 |
| S | .07 | .089 | trace. |

Four iron and manganese ores, Stuart estate, Lick Mountain, near Wytheville, Va. From J. W. Reardin.

[Analyses by J. E. Whitfield.]

| | A. | B. | C. | D. |
|---|---|---|---|---|
| Fe | 2.92 | 2.57 | 1.98 | 48.988 |
| Mn | 51.05 | 41.89 | 57.67 | 4.54 |
| P | .161 | .035 | .009 | .394 |
| S | trace. | .09 | .067 | .056 |
| Insoluble | 4.32 | 4.05 | 1.85 | 10.34 |

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Also three ores from the same estate, sent in by P. B. Thompson, jr. Same analyst.

| | A. | B. | C. |
|---|---|---|---|
| Fe | 34.05 | 38.01 | 3.96 |
| Mn | 4.93 | 15.23 | 44.60 |
| P | .118 | .05 | 0.45 |
| S | .083 | .088 | trace. |
| Insoluble | 34.59 | 9.31 | 15.81 |

Ores collected by Prof. J. R. Procter. Analyses partly by J. E. Whitfield, partly by C. Catlett.

A. From Scott County, Va.: 1, Anderson lands, near top of Clinch Mountain, southern slope, 1,150 feet above the railroad water-tank; 2, James Boatwright's land, east side of Stony Creek, Buffalo Ridge; 3, Clinch River Hills, land of J. C. Taylor's heirs, north side of the river, 3½ miles above Stock Creek; 4, Slip Hill ore, where North Fork of Clinch River cuts through Purchase Ridge.

[Analyses 1, Catlett; 2, 3, 4, Whitfield.]

| | No. 1. | No. 2. | No. 3. | No. 4. |
|---|---|---|---|---|
| Fe | 51.98 | 47.22 | 49.79 | 11.543 |
| Mn | 4.60 | trace. | trace. | none. |
| P | 1.406 | .093 | .205 | .275 |
| S | .086 | .119 | .008 | .08 |
| Insoluble | 2.07 | 25.56 | 17.332 | 59.306 |

B. From Wise County, Va.: 1, 2, 3, Big Stone Gap, top, middle, and bottom layers; 4, 1¼ miles from Big Stone Gap; 5, lands of Virginia Coal and Iron Company. All the deposits are on the south slope of Wallen's Ridge.

[Analyses by Whitfield.]

| | 1, top. | 2, middle. | 3, bottom. | 4. | 5. |
|---|---|---|---|---|---|
| Fe | 6.65 | 49.44 | 49.44 | 39.76 | 52.00 |
| Mn | .30 | trace. | none. | .47 | trace. |
| P | .096 | .015 | .122 | .260 | .165 |
| S | .136 | .132 | .135 | .085 | .08 |
| Insoluble | 80.38 | 21.75 | 24.52 | 36.64 | 11.17 |

C. From Lee County, Va.: 1, A. J. Ely's land, north slope of Poor Valley Ridge, near Pennington Gap; 2, land of W. M. Pennington, near Pennington Gap.

[Whitfield, analyst.]

| | No. 1. | No. 2. |
|---|---|---|
| Fe | 52.82 | 20.76 |
| Mn | trace. | trace. |
| P | .124 | .33 |
| S | .115 | .079 |
| Insoluble | 17.92 | 64.43 |

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D. Iron ore, three miles east of Pineville, on north slope of Pine Mountain, Bell county, Ky.

[Analysis by Catlett.]

| | |
|---|---|
| Fe | 43.32 |
| Mn | 1.27 |
| P | .120 |
| S | .342 |
| $SiO_2$ | 13.48 |

E. Supposed iron ore, one-half mile west of top of Flint Hill, two and one-half miles from North Carolina line, on the waters of Elk, Carter County, Tenn.

[Whitfield, analyst.]

| | |
|---|---|
| Insoluble | 88.48 |
| Fe | 5.83 |
| Mn | 1.35 |
| P | .043 |
| S | .039 |

F. Iron ores from Claiborne County, Tenn.: 1, outcrops 100 yards east of the Russell shaft, four miles southwest of Cumberland Gap; 2, Oty shaft, east end of Double Mountain, one and one half miles west of Cumberland Mountain; 3, Van shaft, southern slope of Double Mountain, one-half mile west of Gap Creek, two and one-half miles southwest of Cumberland Gap; 4, red fossil ore, three miles east of Big Creek Gap, southern slope of Cumberland Mountain; 5, red fossil ore, 200 yards east of Big Creek, 175 feet above creek, on southern slope of mountain, Big Creek Gap.

[Analyses by Catlett.]

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. |
|---|---|---|---|---|---|
| $SiO_2$ | 4.28 | 7.43 | 19.79 | 6.70 | 5.66 |
| Fe | 55.16 | 54.94 | 44.71 | 54.54 | 53.83 |
| Mn | .09 | .30 | trace. | .43 | .53 |
| P | .910 | .124 | .108 | .72 | .243 |
| S | .162 | .087 | .269 | .214 | .187 |

G. Ores from Unicoi County, Tenn.: 1, Garland land, on ridge between Rock and Martin's Creeks; 2, land of W. and M. Peebles, northern slope of Little Iron Mountain, near top of spur; 3, northwest spur of Unaka Mountains, one and one-half miles south of Irwin; 4, old mine on the Farnum land, at base of hill opposite mouth of Sciatha Creek; 5, divide between the waters of Rock and Dix Creeks, Hann tract; 6, Bell lands, on ridge west of Rock Creek, one and one-half miles east of Irwin, 700 feet above Irwin; 7, land of W. F. Norris, six miles from Johnson City, three-fourths of a mile southeast of Buffalo Creek; 8, west end of Little Iron Mountain, about one mile west of

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mill, near top of hill; 9, one-fourth mile southeast from Blue Spring, on waters of Indian Creek.

[Analyses by Whitfield.]

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. |
|---|---|---|---|---|---|---|
| Fe | 46.41 | 54.69 | 2.70 | 23.55 | 41.63 | 56.32 |
| Mn | 3.47 | trace. | 44.94 | 32.98 | 12.13 | trace. |
| P | .741 | 1.102 | .282 | .551 | 1.237 | 1.432 |
| S | .077 | none. | none. | none. | .057 | .059 |
| Insoluble | 5.06 | 6.51 | 3.14 | 5.11 | 3.85 | 3.32 |

[Analyses by Catlett.]

| | No. 7. | No. 8. | No. 9. |
|---|---|---|---|
| Fe | 2.04 | 46.37 | 51.40 |
| Mn | 39.37 | .38 | 3.01 |
| P | .116 | .509 | .761 |
| S | trace. | .106 | .092 |
| $SO_2$ | 18.10 | 3.77 | 6.26 |

Iron ore, Cranberry Bed, Mitchell County, N. C.

[Analysis by Whitfield.]

| | |
|---|---|
| Fe | 51.65 |
| Mn | .36 |
| P | trace. |
| S | .081 |
| Insoluble | 19.95 |
| $TiO_2$, Ni | traces. |

Ores collected by L. C. Johnson in Louisiana: 1, Miller's Bluff, Bossier Parish; 2, Aubrey, Claiborne Parish; 3, Gilmer field, Phelps Lake, Bossier Parish.

[Analyses by Catlett.]

| | No. 1. | No. 2. | No. 3. |
|---|---|---|---|
| Fe | 38.35 | 43.17 | 49.97 |
| P | .18 | 1.65 | .62 |
| S | .34 | .056 | .08 |
| Insoluble | 21.40 | 11.42 | 12.15 |

Ores from Arkansas, received from Hon. W. C. Whitthorne, from a mountain ridge crossing the line between Polk and Montgomery Counties, between the two Salinas Creeks: A, manganese; B, iron ore.

[Analyses by C. Catlett.]

| | A. | B. |
|---|---|---|
| $SiO_2$ | 4.64 | .94 |
| Mn | 38.33 | 1.32 |
| Fe | 18.68 | 54.30 |
| S | .170 | .162 |
| P | .561 | 1.826 |

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Iron ore from Wood County, Wisconsin. Section 32, T. 24, R. 4 E. Received from T. E. Nash.

[Analyzed by J. E. Whitfield.]

| | |
|---|---|
| Fe | 22.15 |
| Mn | trace. |
| S | .008 |
| P | .030 |
| Insoluble | 57.70 |

Manganese ore (impure rhodochrosite), from Llanbedr, Harlech, Merionethshire, Wales. Analyzed by T. M. Chatard, at request of Dr. D. T. Day, for purposes of comparison with certain American material.

| | |
|---|---|
| $CO_2$ | 19.04 |
| Mn | 31.12 |
| $Al_2O_3$ | 7.63 |
| Fe | 4.02 |
| $SiO_2$ | 21.69 |

## COAL AND COKE.

Two samples of coke from near Piedmont, W. Va. Received from G. W. Harrison.

[Analyses by C. Catlett.]

| | Thomas mine. | Davis mine. |
|---|---|---|
| Moisture | .47 | .25 |
| Volatile carbon | 2.39 | 2.24 |
| Fixed carbon | 87.14 | 89.23 |
| Ash | 10.00 | 8.28 |
| | 100.00 | 100.00 |
| S | .721 | .645 |

Two samples of coal from near Piedmont, W. Va. Received from Hon. H. G. Davis.

[Analyses by C. Catlett.]

| | Elk Garden mine. | Davis mine. |
|---|---|---|
| Moisture | .76 | .70 |
| Volatile carbon | 19.39 | 22.03 |
| Fixed carbon | 72.99 | 70.53 |
| Ash | 6.86 | 6.74 |
| | 100.00 | 100.00 |
| S | .880 | .924 |

Ash white, coke silver gray and porous.

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Supposed anthracite from near Romney, W. Va. Received from A. W. Kercheval. A shale.

[Analyzed by C. Catlett.]

| | |
|---|---|
| Moisture | .68 |
| Volatile carbon | 7.32 |
| Fixed carbon | 5.37 |
| Ash | 86.63 |

Three samples coal, Sharp bank, East Fork of Big Creek, Claiborne County, Tenn. Received from J. R. Procter.

[Analyzed by C. Catlett.]

| | Top. | Middle. | Bottom. |
|---|---|---|---|
| Moisture | 2.40 | 2.10 | 1.78 |
| Volatile carbon | 36.81 | 33.76 | 39.14 |
| Fixed carbon | 57.88 | 51.29 | 56.00 |
| Ash | 2.91 | 12.85 | 3.08 |
| | 100.00 | 100.00 | 100.00 |
| S | 1.087 | 1.15 | 2.30 |

Coke hard to burn; dark in color; ash brown.

Coal from Pend d'Oreille, Oregon. From Hon. J. K. Jones.

[Analysis by C. Catlett.]

| | |
|---|---|
| Moisture | 7.56 |
| Volatile carbon | 52.55 |
| Fixed carbon | 30.43 |
| Ash | 9.46 |
| | 100.00 |
| S | .65 |

## EFFLORESCENCE ON SANDSTONE, FROM CLIFF CREEK, GUNNISON COUNTY, COLO.

[Collected by Whitman Cross; analyzed by L. G. Eakins.]

| | Soluble in water. | | Insoluble. |
|---|---|---|---|
| $Al_2O_3$ | trace. | $SiO_2$ | 55.09 |
| CaO | trace. | $Al_2O_3$ | 9.75 |
| MgO | 5.42 | $Fe_2O_3$ | 1.23 |
| $SO_3$ | 10.31 | CaO | .30 |
| | | MgO | .39 |
| | | Alkalies | undet. |
| | 15.73 | | 66.76 |

| | |
|---|---|
| Water | 16.88 |
| Soluble | 15.73 |
| Insoluble | 66.76 |
| | 99.37 |

The soluble part is essentially $MgSO_4$, $7H_2O$.

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## COMMON SALT, FROM HUTCHINSON, KANSAS.

[Received from Hon. P. B. Plumb, analyzed by T. M. Chatard.]

| | |
|---|---|
| $H_2O$ | .92 |
| Insoluble | .09 |
| $CaSO_4$ | 1.47 |
| $MgCl_2$ | .25 |
| NaCl | 97.27 |
| | 100.00 |

## WATER FROM LINCOLN COUNTY, N. C.

**Spring on the farm of Willis E. Hall, 3 miles from Lowesville post-office, and 20 miles from Charlotte.**

[Analysis by F. W. Clarke. Stated in grammes per litre. Total solids, 0.642 gram.]

| | Found. | Per cent. of total solids. | | Hypothetical combination. |
|---|---|---|---|---|
| $SiO_2$ | .0385 | 5.99 | $SiO_2$ | .0385 |
| Cl | .0029 | .45 | $CaSO_4$ | .4716 |
| $SO_4$ | .3329 | 51.86 | $CaCO_3$ | .0318 |
| Ca | .1514 | 23.58 | $MgCO_3$ | .0328 |
| Mg | .0094 | 1.47 | KCl | .0042 |
| Na | .0267 | 4.16 | NaCl | .0015 |
| K | .0022 | .34 | $Na_2CO_3$ | .0601 |
| $CO_3$, difference | .0780 | 12.15 | | .6405 |
| | .6420 | 100.00 | | 99.77 per cent. of total. |

## SURFACE DRAINAGE WATER, ST. AUGUSTINE, FLA.

[Collected by William Kennish; analyzed by T. M. Chatard. Stated in grammes per liter.]

| | Found. | Per cent. of total solids. | | Hypothetical combination. |
|---|---|---|---|---|
| $SiO_2$ | .0146 | 2.40 | $SiO_2$ | .0146 |
| $Al_2O_3+Fe_2O_3$ | .0015 | .25 | $Fe_2O_3$, $Al_2O_3$ | .0015 |
| Ca | .0796 | 13.12 | NaCl | .1625 |
| Mg | .0166 | 2.74 | KCl | .0188 |
| Na | .0639 | 10.53 | $CaSO_4$ | .0742 |
| K | .0098 | 1.61 | $CaH_2C_2O_6$ | .2341 |
| $SO_4$ | .0524 | 8.64 | $MgH_2C_2O_6$ | .1009 |
| Cl | .1076 | 17.74 | | |
| $CO_3$ | .2450 | 40.40 | | |
| H in bicarbonates | .0042 | .69 | | |
| | .5952 | | | |
| Deficit of $CO_3$ | .0114 | 1.88 | | |
| | .6066 | 100.00 | | .6066 |

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## WATER FROM SPRING AT M'LEANSBOROUGH, ILL.

[Received from S. W. Heard; analyzed by R. B. Riggs. Stated in grammes per liter.]

| | Found. | Per cent. of total solids. | | Hypothetical combination. |
|---|---|---|---|---|
| $SO_4$ | 3.0040 | 59.59 | KCl | .0220 |
| $CO_3$ | .7008 | 13.90 | NaCl | .0396 |
| Cl | .0345 | .68 | $Na_2SO_4$ | .8433 |
| $SiO_2$ | .0142 | .28 | $MgSO_4$ | 2.2340 |
| $Al_2O_3$ | trace. | | $CaSO_4$ | .9166 |
| Ca | .5420 | 10.75 | $CaCO_3$ | .1924 |
| Mg | .4468 | 8.86 | $CaH_2C_2O_6$ | .7903 |
| Na | .2888 | 5.73 | $SiO_2$ | .0142 |
| K | .0115 | .21 | | |
| | 5.0426 | 100.00 | | 5.0524 |
| H, bicarbonate | .0098 | | | |
| | 5.0524 | | | |

## WATER FROM LEBANON, LACLEDE COUNTY, MO.

[From a well 1,000 feet deep. Received from Hon. R. P. Bland; analyzed by L. G. Eakins. Stated in grammes per liter.]

| | Found. | Per cent. of total solids. | | Hypothetical combination. |
|---|---|---|---|---|
| $SiO_2$ | .0112 | 3.90 | $SiO_2$ | .0112 |
| $Al_2O_3$ | .0032 | 1.11 | $Al_2O_3$ | .0032 |
| Fe | trace. | | NaCl | trace. |
| Ca | .0326 | 11.35 | $MgSO_4$ | .0060 |
| Mg | .0163 | 5.68 | $FeH_2C_2O_6$ | trace. |
| Na | .0127 | 4.42 | $MgH_2C_2O_6$ | .0917 |
| $SO_4$ | .0048 | 1.67 | $CaH_2C_2O_6$ | .1315 |
| Cl | trace. | | $NaHCO_3$ | .0370 |
| $CO_3$ | .2030 | 70.69 | $Na_2CO_3$ | .0066 |
| H, bicarbonate | .0034 | 1.18 | | |
| | .2872 | 100.00 | | .2872 |

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## TWO SPRINGS AT HOMINY HILL, ARK.

[Received from Hon. A. H. Garland. Analyses by J. E. Whitfield. Stated in grammes per liter.]

### A. OLD OR UPPER SPRING.

| | Found. | Per cent. of total solids. | | Hypothetical combination. |
|---|---|---|---|---|
| $SiO_2$ | .0122 | 7.21 | $SiO_2$ | .0122 |
| Fe, Al | traces. | | $CaSO_4$ | .0058 |
| Br, I | none. | | $CaH_2C_2O_6$ | .0984 |
| $B_2O_3$ | none. | | $MgH_2C_2O_6$ | .0207 |
| Cl | trace. | | $KHCO_3$ | .0103 |
| $SO_4$ | .0041 | 2.42 | $NaHCO_3$ | .0219 |
| $CO_2$ | .1117 | 65.98 | | |
| Ca | .0260 | 15.36 | | |
| Mg | .0034 | 2.01 | | |
| K | .0040 | 2.36 | | |
| Na | .0060 | 3.54 | | |
| Li | trace. | | | |
| $NH_4$ | none. | | | |
| H, bicarbonate | .0019 | 1.12 | | |
| | .1693 | 100.00 | | .1693 |
| Free $CO_2$ | .0276 | | Free $CO_2$ | .0276 |

### B. NEW OR LOWER SPRING.

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | .0100 | 9.39 | $SiO_2$ | .0100 |
| Fe | trace. | | $CaSO_4$ | .0121 |
| Al | none. | | $CaH_2C_2O_6$ | .0535 |
| Br, I, $B_2O_3$ | none. | | $MgH_2C_2O_6$ | .0146 |
| Cl | trace. | | $KHCO_3$ | .0031 |
| $SO_4$ | .0085 | 7.98 | $NaHCO_3$ | .0131 |
| $CO_2$ | .0629 | 59.13 | | |
| Ca | .0168 | 15.79 | | |
| Mg | .0024 | 2.25 | | |
| K | .0012 | 1.13 | | |
| Na | .0036 | 3.39 | | |
| Li | trace. | | | |
| $NH_4$ | none. | | | |
| H, bicarbonate | .0010 | .94 | | |
| | .1064 | 100.00 | | .1064 |
| Free $CO_2$ | .0091 | | Free $CO_2$ | .0091 |

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## WATER FROM A SPRING NEAR DENVER, COLO.

[Received from Sidney Williams; analyzed by L. G. Eakins. Stated in grammes per kilo. Specific gravity 1.063, at 20°.8.]

| | Found. | Per cent. of total solids. | | Hypothetical combination. |
|---|---|---|---|---|
| $SiO_2$ | .0290 | .05 | KCl | .2542 |
| Cl | 1.5862 | 2.62 | NaCl | 2.4143 |
| $SO_4$ | 43.9675 | 72.56 | $Na_2SO_4$ | 18.0629 |
| Al, Fe | traces. | | $MgSO_4$ | 38.7306 |
| Ca | .3214 | .53 | $CaSO_4$ | 1.0929 |
| Mg | 7.7461 | 12.79 | $SiO_2$ | .0290 |
| K | .1331 | .22 | | |
| Na | 6.8006 | 11.23 | | |
| Li | trace. | | | |
| | 60.5839 | 100.00 | | 60.5839 |
| $CO_2$ | .2101 | | | |
| Album. $NH_3$ | .0050 | | | |
| Free $NH_3$ | trace. | | | |

## MATILIJA HOT SPRINGS, NEAR SAN BUENAVENTURA, CAL.

[Received from Dr. Stephen Bowers; analysis by R. B. Riggs. Stated in grammes per liter.]

| | Found. | Per cent. of total solids. | | Hypothetical combination. |
|---|---|---|---|---|
| $SiO_2$ | .0088 | .53 | KCl | .0622 |
| $SiO_2$ | .0412 | 2.51 | NaCl | 1.3876 |
| Cl | .8768 | 53.20 | $MgCl_2$ | .0068 |
| $SO_4$ | .0169 | 1.02 | $MgSO_4$ | .0073 |
| $CO_2$ | .0579 | 3.51 | $CaSO_4$ | .0160 |
| Ca | .0650 | 3.94 | $CaCO_3$ | .0965 |
| Mg | .0034 | .21 | $CaSiO_3$ | .0629 |
| Na | .5456 | 33.11 | $SiO_2$ | .0088 |
| K | .0325 | 1.97 | | |
| | 1.6481 | 100.00 | | 1.6481 |

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## LIBRARY CATALOGUE SLIPS.

**United States.** *Department of the interior.* (*U. S. geological survey*).
Department of the interior | — | Bulletin | of the | United States | geological survey | no. 58 | [Seal of the department] |
Washington | government printing office | 1890

Series title.

*Second title:* United States geological survey | J. W. Powell, director | — | The | glacial boundary | in | western Pennsylvania, Ohio, Kentucky, | Indiana, and Illinois | by | George Frederick Wright | with an introduction by Thomas Chrowder Chamberlin | [Vignette] |
Washington | government printing office | 1890
8°. 112 pp. 8 pl.

**Wright** (George Frederick).
United States geological survey | J. W. Powell, director | — | The | glacial boundary | in | western Pennsylvania, Ohio, Kentucky, | Indiana, and Illinois | by | George Frederick Wright | with an introduction by Thomas Chrowder Chamberlin | [Vignette] |
Washington | government printing office | 1890
8°. 112 pp. 8 pl.
[UNITED STATES. *Department of the interior.* (*U. S. geological survey*). Bulletin 58].

Author title.

Title for subject entry.

United States geological survey | J. W. Powell, director | — | The | glacial boundary | in | western Pennsylvania, Ohio, Kentucky, | Indiana, and Illinois | by | George Frederick Wright | with an introduction by Thomas Chrowder Chamberlin | [Vignette] |
Washington | government printing office | 1890
8°. 112 pp. 8 pl.
[UNITED STATES. *Department of the interior.* (*U. S. geological survey*). Bulletin 58].

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# ADVERTISEMENT.

[Bulletin No. 60.]

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The publications of the United States Geological Survey are issued in accordance with the statute approved March 3, 1879, which declares that—

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization: And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

On July 7, 1882, the following joint resolution, referring to all Government publications, was passed by Congress:

"That whenever any document or report shall be ordered printed by Congress, there shall be printed, in addition to the number in each case stated, the 'usual number' (1,900) of copies for binding and distribution among those entitled to receive them."

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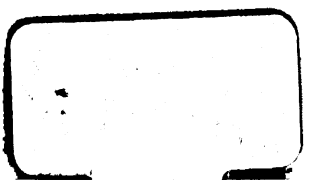

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